FRONTAL FAULT ZONE OF THE WICHITA MOUNTAINS: IDENTIFICATION AND CHARACTERIZATION OF A FAULT-ASSOCIATED LATERAL SEAL

By

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FAULT-ASSOCIATED

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CHAPTER I

INTRODUCTION

General Statement

Pressure compartments are found in sedimentary basins throughout the world. Compartments are two-component systems comprising a rock of relatively good porosity and permeability surrounded by a low permeability seal (Al-Shaieb and others, 1994b). They typically occur below 3050 m (10,000 ft) and are instantly recognized by their abnormal fluid pressures.

The seals surrounding these compartments are classified in terms of their spatial relationship to the compartment. Thus, compartments are bounded above and below by top and bottom (or basal) seals. These horizontal seals are often parallel to bedding. Compartments are bounded on their sides by lateral (or vertical) seals. Lateral seals may be absent when closure occurs by convergence of the top and basal seals (Ortoleva and others, 1995). Lateral seals are generally at high angles to bedding.

Seals possess sufficiently low permeabilities such that measurable pressure differentials have been sustained over geologic time. In fact, Deming (1994) showed that the minimum permeability needed for a geological unit to act as a pressure seal for more than 1 m.y. is 10^{-21}-10^{-23} m^2 (10^{-6}-10^{-8} md).

In the Anadarko Basin, a basin-wide, overpressured, and completely sealed compartment, termed the mega-compartment complex (MCC), exists in sedimentary rocks roughly below 2290 to 3050 m (7500 to 10,000 ft) (Figure 1) (Al-Shaieb, 1991). Controlled primarily by diagenetic processes, the top seal is relatively flat and dips gently to the west-southwest, cutting across stratigraphy (Tigert and Al-Shaieb, 1990). The basal seal is formed by the laterally extensive Woodford Shale (Al-Shaieb and others, 1994b). Convergence of the top and basal seals encloses the compartment to the northeast, north, and northwest. To the south, a zone of extensive cementation associated with the Wichita frontal fault zone forms a low-porosity fairway that functions as a lateral seal. The southern lateral seal is the primary focus of this research.

The delineation of the cemented zone which forms the lateral seal is critical to successful oil and gas exploration along the southern margin of the basin. Reserve potential in overpressured strata is drastically reduced adjacent to the fault zone but increases towards the axis of the basin.

Objectives

The present study is part of a Gas Research Institute project at Oklahoma State University to examine compartmentalized and non-compartmentalized reservoirs within the deep Anadarko Basin. The primary objectives of this investigation are:

1. Determine the position of select fault-adjacent reservoir rocks relative to the overpressured MCC using pressure data obtained from scout tickets and petroleum industry data bases.

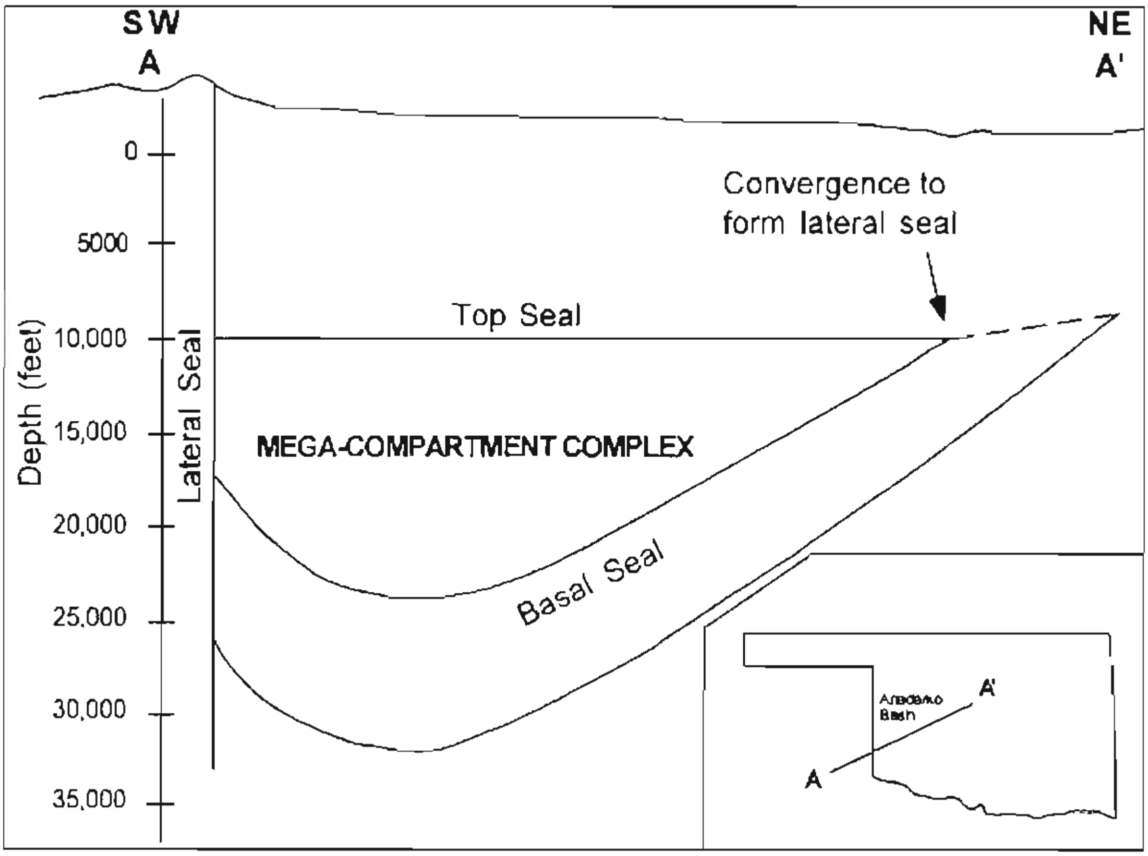


Figure 1. Schematic diagram illustrating the MCC of the Anadarko Basin.

2. Couple normal petrographic techniques with x-ray diffraction to establish the depositional and diagenetic histories of these rocks.
3. Identify strata affected by cementation adjacent to the frontal fault zone of the Wichita Mountains and relate areas of intense cementation to overpressuring phenomena.
4. Examine the processes and fluid migration pathways by which porosity was preserved or occluded in reservoirs associated with the frontal fault zone of the Wichita Mountains.
5. Demonstrate that the cemented interval along the frontal fault zone of the Wichita Mountains forms a low porosity fairway that functions as the southern lateral seal of the MCC.
6. Comment on the implications for oil and gas exploration along the frontal fault zone of the Wichita Mountains.

Location of Study Area

The area of this investigation encompasses portions of Beckham, Washita, Roger Mills and Kiowa Counties, Oklahoma and Wheeler County, Texas (Figure 2). Core availability played a major role in determination of the study area, for cores in the vicinity of the frontal fault zone are limited. This region corresponds to the northern (leading) edge of the Wichita Uplift and the southern flank of the Anadarko Basin.

Methods of Investigation

Integration of written, numerical, and petrographic information was essential in order to fully characterize the fault-associated lateral seal of the MCC. A literature

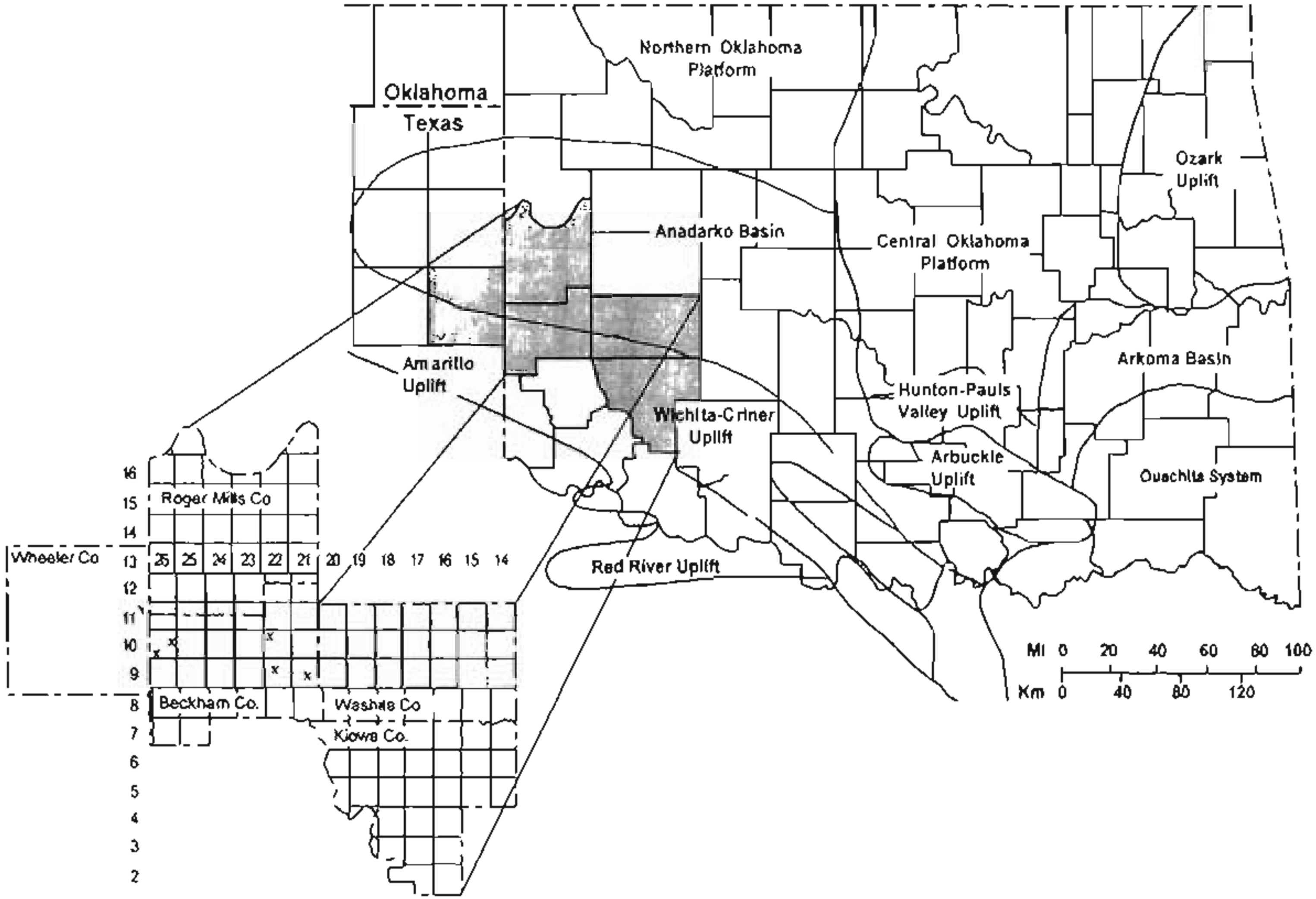


Figure 2. Tectonic map showing the major structural features of Oklahoma and the location of the study area along the northern edge of the Wichita Uplift and the southern flank of the Anadarko Basin. Core locations indicated by an (x) (modified after Al-Shaieb and Shelton, 1977; Arbenz, 1956).

search regarding the geology of the western Anadarko Basin was conducted to establish the tectonic and depositional framework of the region and determine pressure and temperature domains. Previous investigations regarding abnormal formation pressure, reservoir compartmentalization, and sealing mechanisms were incorporated into the study.

Pressure data obtained from scout tickets and petroleum industry data bases (Amoco, Dwights Energydata, Inc.) were used to calculate pressure gradients within the study area. Based on the calculated gradients, the reservoir rocks were divided into three main categories: (1) normally pressured rocks above the MCC, (2) overpressured rocks within the MCC, and (3) normally pressured rocks below the MCC.

Wire-line well logs were examined to determine the extent of the low-porosity fairway associated with the frontal fault zone of the Wichita Mountains. Combination Neutron-Density logs were used to quantify porosity in reservoir rocks above, within, and below the overpressured MCC.

The architecture and character of strata above, within, and below the overpressured interval were investigated through detailed examination of cores in the vicinity of the frontal fault zone. Cores provided by the petroleum industry are generally restricted to areas where hydrocarbons are known to exist. The frontal fault zone of the Wichita Mountains is characterized as a high risk area. Therefore, the number of cores available for study was limited by the lack of drilling activity along the fault zone. Analysis of obtained cores focused on the identification of sedimentary structures, textures, and lithofacies.

The petrographic investigation involved the examination of 56 thin sections under the polarizing microscope and x-ray diffraction. Thin section analysis concentrated on the identification and characterization of detrital constituents, diagenetic imprints, and porosity. Each sample was impregnated with blue epoxy to assist in the identification of porosity. Quantitative measurements were obtained through point-counting (10 points per sample).

Above the overpressured interval, petrographic analysis was conducted on four samples from the Shell Whitledge No. 1-8 well and four from the Exxon Felton No. 1-6 well. Examination of thin sections within the MCC included seven samples from the Gulf Community Paine No. 1 well, two samples from the GHK Kennemer No. 1-22 well, and ten samples from the Hunt Bryant No. 1-57 well. The normally pressured interval below the MCC was represented by twenty-nine samples from the Apexco (Natomas) Green No. 1 well.

CHAPTER II

GEOLOGIC SETTING

Structural Setting and Tectonics

Containing more than 12,000 m (40,000 ft) of Cambrian through Permian sediments, the Anadarko Basin is the deepest Paleozoic sedimentary basin on the North American craton (Johnson, 1989). The basin is located in western Oklahoma and the northern Texas Panhandle and covers an area of 90,639 km^2 (35,000 mi^2) (Figure 2). It is bounded to the east by the Nemaha Ridge and to the south by the Wichita-Amarillo Mountain front. To the west and north, the basin is flanked by shallow platform areas (Al-Shaieb and others, 1994b).

The Anadarko Basin is an elongate, west-northwest trending basin which is structurally deepest along its southern margin (Perry, 1989). This cross-sectional asymmetry results from the complex Wichita fault zone separating the basin from the Wichita-Amarillo Uplift (Al-Shaieb and others, 1994b). The Anadarko Basin and Wichita Uplift are two of the major structural features found in the series of west-northwesterly oriented basins and uplifts within the southern Mid-Continent (McConnell and others, 1990).

The Anadarko Basin occupies the northern flank of the southern Oklahoma aulacogen, which has a geologic history ranging from Late Proterozoic to Late Paleozoic

(Figure 3) (Perry, 1989). Reactivation of faults initiated during aulacogen formation is partially responsible for the structural features of the modern Anadarko Basin. Therefore, the structural evolution of the Anadarko Basin and Wichita Uplift is closely related to the development of the aulacogen.

Oklahoma was first recognized as an aulacogen by Schatski (1946). Aulacogens are generally described as "long-lived, deeply subsiding sedimentary troughs, often fault bounded, that extend at high angles from the margins towards the interiors of cratons" (Dickinson, 1974). They represent a failed arm of rifting, or zones of continental crust which were extended through normal faulting, that did not thin sufficiently to allow the formation of mafic oceanic crust. Hoffman and others (1974) considered the evolution of an aulacogen within a cratonic platform to be genetically linked to the opening and closing of an associated oceanic basin. Wickham (1978) states that aulacogens develop in three stages (Figure 4): (1) the rifting stage, which is associated with intrusive and extrusive igneous activity, (2) the subsidence stage, and (3) the deformation stage, in which local basins and uplifts form. These stages represent the cratonic equivalent of a complete Wilson cycle.

In Late Proterozoic to Early Cambrian time, a rift-rift-rift triple junction developed in response to the effects of an underlying mantle plume (Walper, 1977). Increased heat flow resulted in the formation of an upwarped dome. Extensional stresses in the upwarped dome produced normal faults and grabens near the surface. The grabens divided the uplift into three rifts. Separation across the rifts led to the generation of a rift-rift-rift triple junction (Burke and Dewey, 1973). The rifting process was accompanied by igneous activity and the deposition of coarse continental clastics within the rift

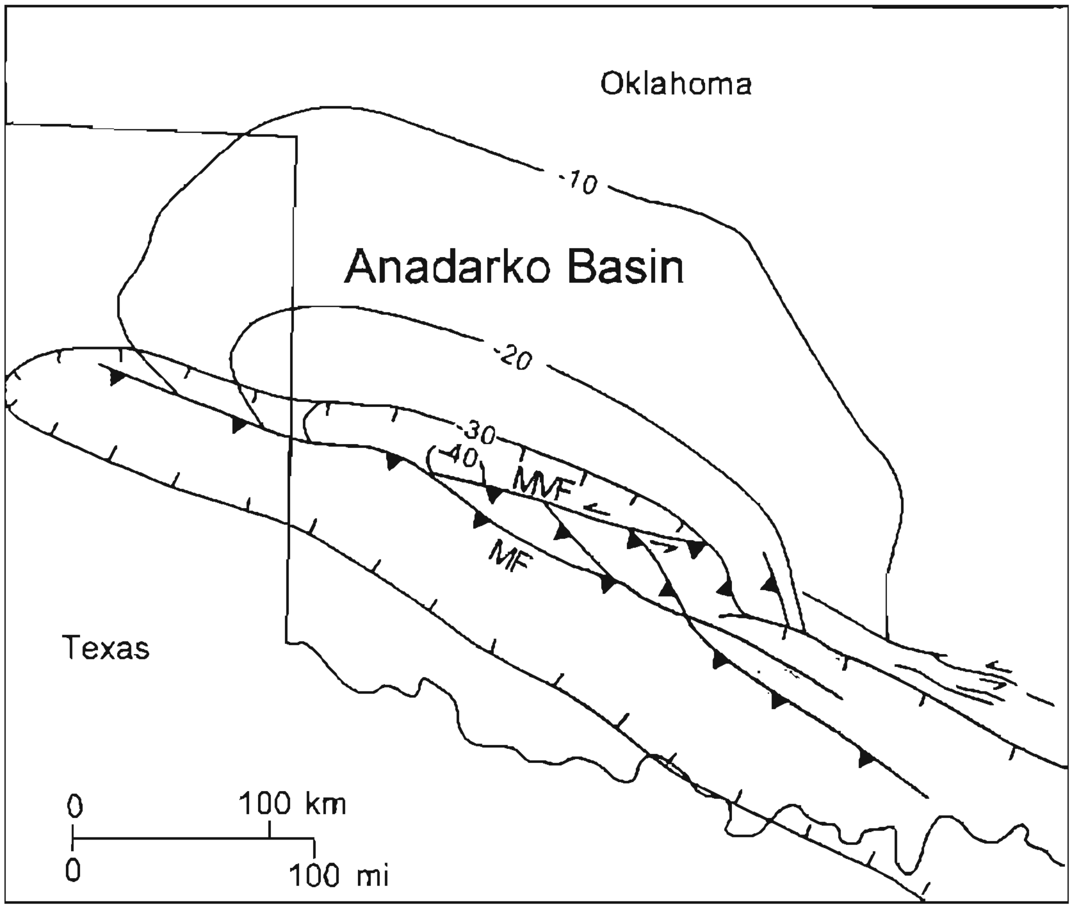


Figure 3. Inferred location and limits of the southern Oklahoma aulacogen (shaded area) and the Anadarko basin. Contours show generalized sedimentary thickness values in thousands of feet below sea level. MVF, Mountain View Fault; MF, Meers Fault (after Perry, 1989).

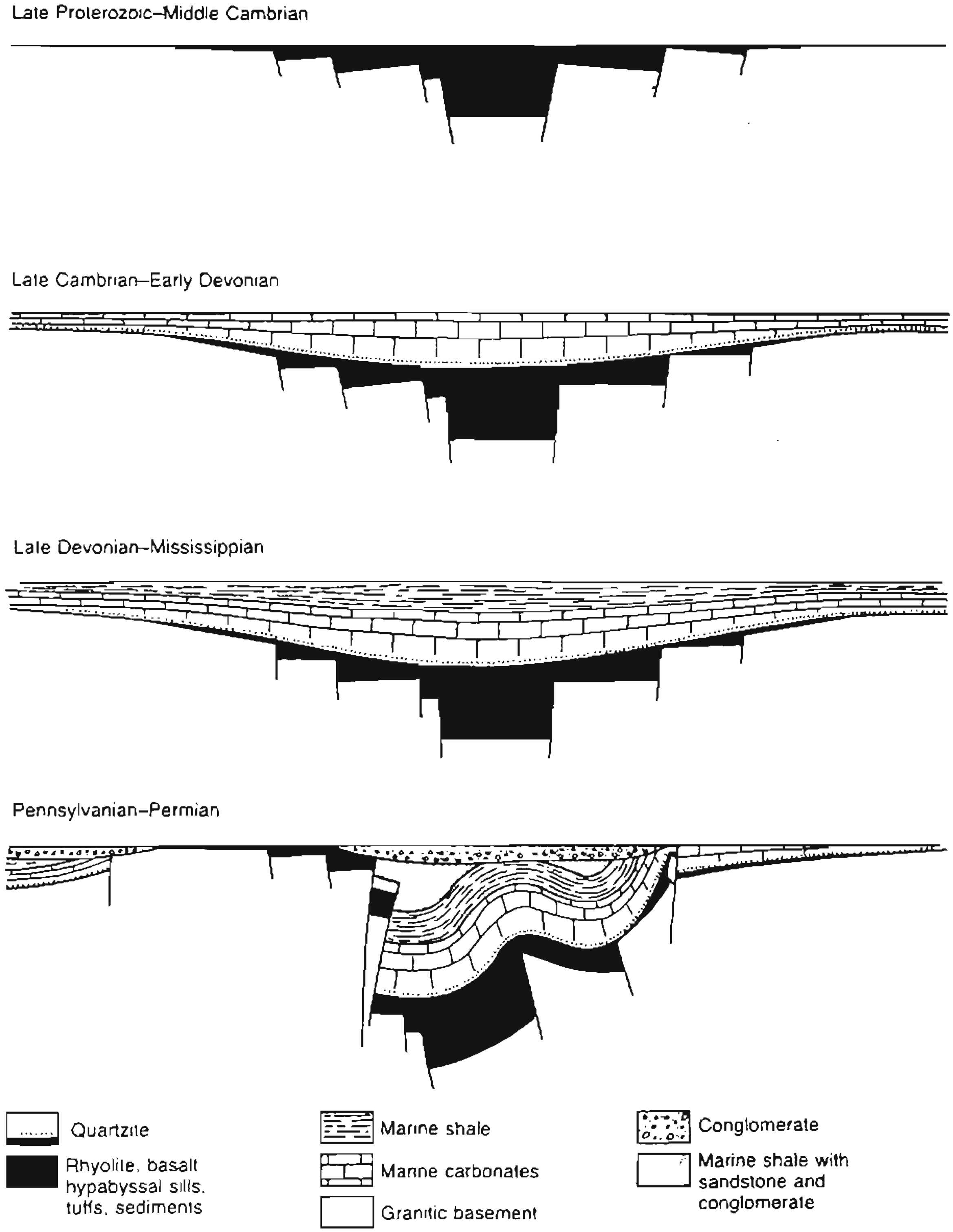


Figure 4. Schematic transverse sections illustrating the evolution of the southern Oklahoma aulacogen (after Ham, 1969).

valleys. Igneous rocks directly related to the early phases of aulacogen development constitute a silicic volcano-plutonic complex and consist of the Carlton Rhyolite and Wichita Granite Groups (Hanson and Al-Shaieb, 1980). The granites and rhyolites represent a single pulse of silicic magmatism; both give radiometric ages between 500 and 525 m.y. (Ham and others, 1964; Denison and others, 1966; Muehlberger and others, 1966). The Reagan Sandstone represents the first clastic rocks of the southern Oklahoma aulacogen.

The subsidence stage of the aulacogen was ushered in by the north-northwest transgression of Late Cambrian seas across Oklahoma. From Late Cambrian through Mississippian time, the area of the Anadarko Basin was part of a broad epicontinental sea. This sea, commonly referred to as the Oklahoma Basin, was a broad embayment that received a sequence of thick and extensive carbonates interbedded with thinner shales and sandstones (Johnson, 1989). These strata thickened into protobasins in those areas that would subsequently evolve into the Anadarko, Arkoma, and Ardmore Basins. The depocenter for the Oklahoma Basin eventually became the site of the deep Anadarko Basin and Wichita-Amarillo Uplift (Johnson, 1989).

Subsidence of the aulacogen was accommodated by displacements on the normal faults initiated during the earlier rifting stage (Figure 4). Syndepositional movement of these faults throughout the subsidence stage is evidenced by abnormally large differences in the thickness of some units across these major faults. However, subsequent left-lateral displacements along major faults during Pennsylvanian time may account for these thickness variations.

The deformation stage, which was responsible for the formation of the Anadarko Basin as a separate structural feature, can be divided into two distinct pulses (Perry, 1989). The Wichita Orogeny commenced in Late Mississippian-Early Pennsylvanian time, creating the Anadarko and Ardmore Basins. Faulting commenced at the southeast end of the Anadarko Basin in early Morrowan time (Ham and Wilson, 1967), while farther west, it began in late Morrowan time. Faulting continued throughout the Pennsylvanian and ceased in the Early Permian.

Orogenic movements of the Wichita-Amarillo block and other positive elements (Cimarron Arch, Nemaha Uplift) surrounding the Anadarko Basin involved faulting, folding, uplifting, and downwarping. The tectonism was not accompanied by igneous/metamorphic activity (Johnson, 1989).

The second phase of deformation occurred during Virgilian time and is represented by the Arbuckle orogeny. This stage includes uplift of the Arbuckle Mountains and folding/subsidence of the Ardmore Basin (Webster, 1980).

Tremendous controversy surrounds the deformation stage of the southern Oklahoma aulacogen (Figure 4). Although most authors agree that deformation commenced in the Late Mississippian-Early Pennsylvanian when the North American plate collided with the Afro-South American plate, the structural style of deformation remains unresolved. As a result, several schools of thought have emerged to explain the structural history of the region.

The thrust-like character of the northern margin of the Wichita Uplift can be used to argue for: (1) reverse dip-slip, basement involved thrusting; (2) oblique-slip as either reverse left-slip or left-handed reverse slip; or (3) a combination of separate episodes of left-slip and reverse dip-slip faulting (McConnell, 1989).

Kluth and Coney (1981) proposed that the irregular southern margin of the North American continent influenced the location of Carboniferous deformation. Goldstein (1981) notes similarities between the Laramide block uplifts of the Rocky Mountains and the uplifts of the Ancestral Rocky Mountains. The interpretations of Goldstein (1981), Kluth and Coney (1981), and McConnell (1989) infer that Carboniferous intraplate strains were distributed throughout the Ancestral Rocky Mountains as slip on discrete brittle fault zones bounding separate basement uplifts.

Alternative interpretations have centered upon the concept of megashears, lineaments, or transform faults. These interpretations emphasized the role of strike-slip faults in shaping the tectonic provinces of the southwestern United States (McConnell, 1989).

Budnik (1986) proposed that tectonism within the foreland of the Ouachita orogen could be viewed as a continuous zone of sinistral shear (Wichita megashear) extending from the Arbuckle and Wichita Mountains of Oklahoma to Utah. The Wichita Uplift, therefore, represents a link in the chain of uplifts that formed the megashear. Offset across the boundaries of the uplift would have been similar to that estimated for the megashear (Lemiszki and Brown, 1988). Budnik (1986) suggested that there was as much as 150 km of Carboniferous left slip along the megashear. Separations estimated by Veile (1986) suggest similar displacements. The tectonic implication of the megashear model is that the Wichita-Amarillo Uplift represents a crustal discontinuity which separated the southern part of the North American continent into two sub-plates (McConnell, 1989).

Evans (1979) suggests that the main types of structural deformation can be related to the two principal movements (vertical block uplift and left lateral movement), with left-lateral strike-slip movement occurring after vertical uplift. Deformation related to vertical block uplift is evidenced by a narrow zone where the competent Arbuckle Group conforms with the basement to form a series of step faults that are down to the basin. The competent carbonates of the Meramec-Osage tend to detach into blocks exhibiting a large increase in dip rate. Erosion of the upthrown block provided material for a thick wedge of Pennsylvanian-age carbonates and shales which accumulated on the downthrown side. This type of deformation is found in Beckham County, Oklahoma and Wheeler County, Texas (Evans, 1979).

According to Evans (1979), vertical block uplift was followed by left lateral slip along the faults. Strike-slip motion is observed in the Ardmore Basin-Criner Hills area and is assumed to decrease in magnitude to the west. Assuming the majority of the vertical displacement preceded lateral displacement, 10,668 to 12,192 m (35,000 to 40,000 ft) of sediments are juxtaposed against basement rocks. The north (sedimentary) block is considered to be the plate of principal movement (Evans, 1979).

Local Structural Geology

The study area is characterized by a series of fault blocks with a northwestward tilt intersected by prominent cross-faults (Ham, 1964). The Mountain View Fault, which separates the frontal Wichitas from the Anadarko Basin, and the Meers Fault, which forms the dividing line between the frontal Wichitas and the Wichita Mountains, are the two major features (Figure 5). These large faults were probably initiated during the Cambrian as normal faults bounding the rift valley. They were rejuvenated during the Pennsylvanian and Early Permian (Miller, 1981).

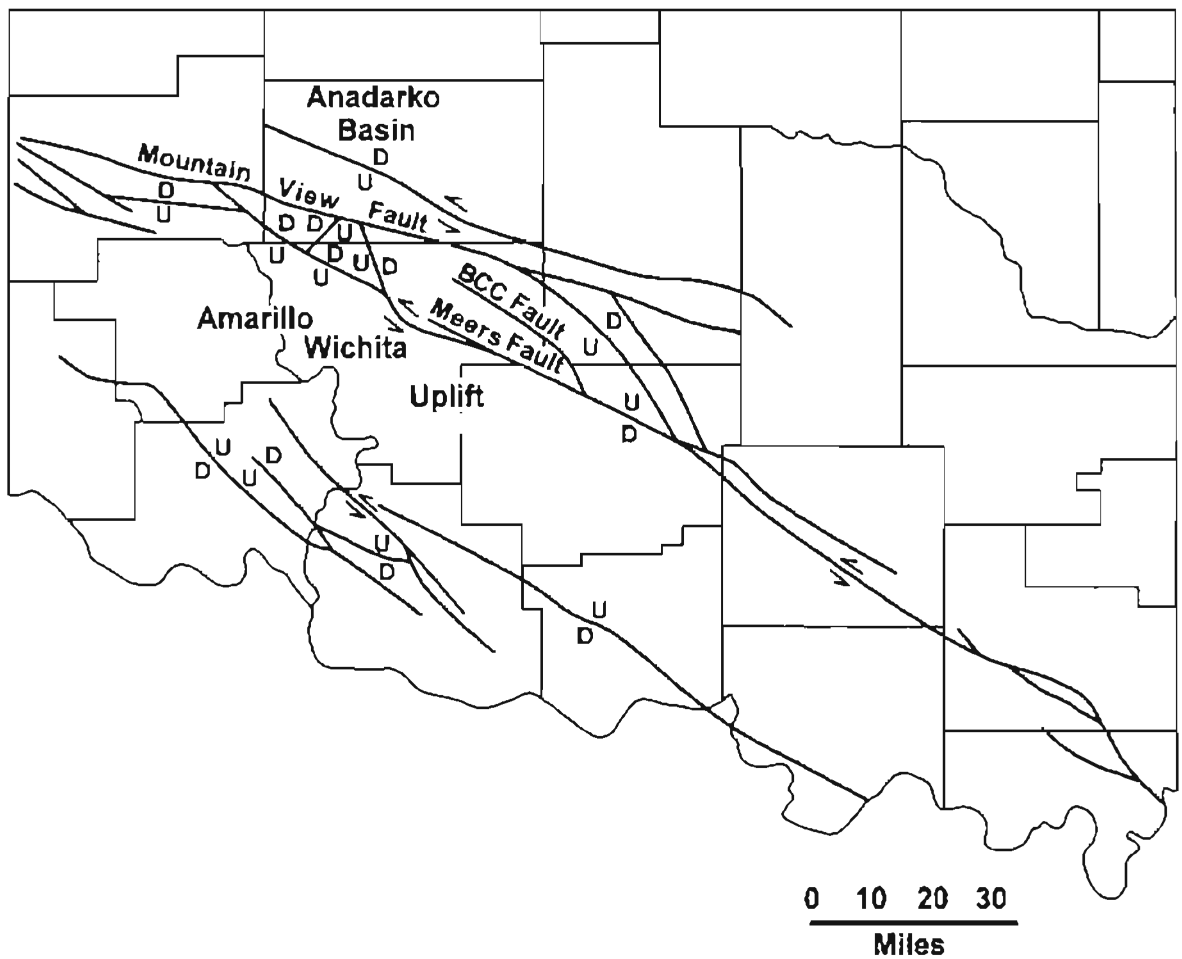


Figure 5. Major structural features in southwestern Oklahoma. The Mountain View Fault and Meers Fault are the two main features (after Ham and others, 1964; Harlton, 1951, 1963, 1972; and Luza, 1988).

CHAPTER III

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

The vertical nature of the lateral seal mandates the inclusion of a large segment of the Anadarko Basin sedimentary sequence. A generalized stratigraphic column spanning Cambrian through Permian time is given in Figure 6. As one might expect when dealing with such a large time span, a wide variety of lithologies are represented. In general, however, the Lower Paleozoic was a period of marine inundation and extensive carbonate sedimentation, while Upper Paleozoic rocks are primarily clastic in nature.

Subsidence of the Anadarko Basin, during the Late Cambrian, resulted in a marine transgression manifested by the deposition of the Upper Cambrian Reagan Sandstone. Until the end of the Lower Ordovician, a similar depositional environment produced a continuous succession of shallow water limestones and dolomites, collectively termed the Arbuckle Group. The dolomites are diagenetic, having formed at the expense of limestone (Johnson, 1989). Total thickness of the Upper Cambrian-Lower Ordovician Arbuckle Group approaches 1524 m (5000 ft) along the depocenter of the basin (Wickham, 1978).

The overlying Middle Ordovician Simpson Group includes green shales, clean sandstones and limestones. With a source to the east-northeast, the Simpson

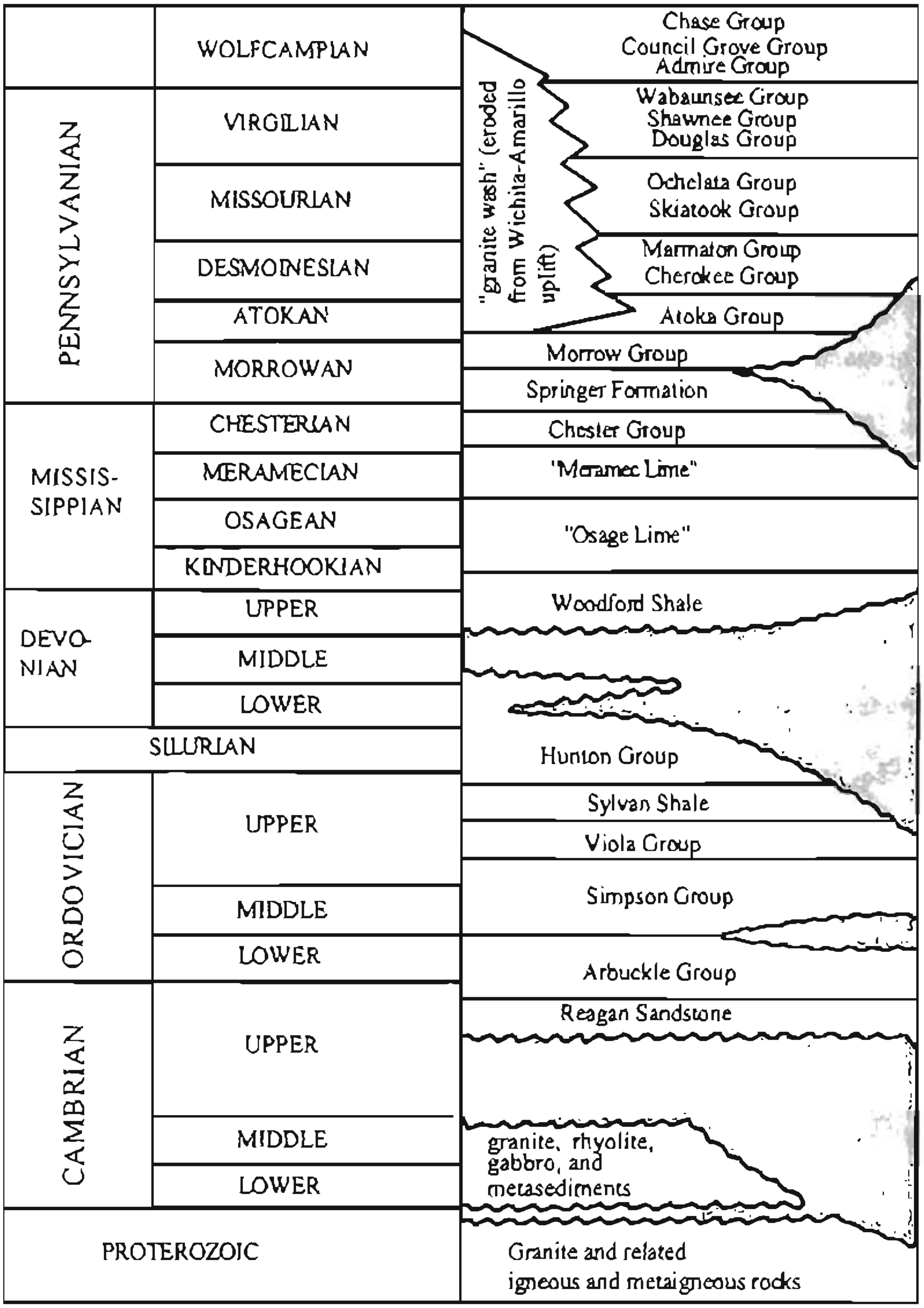


Figure 6. Stratigraphic column for the Anadarko Basin (modified after Johnson, 1989).

Group contains the only clastic rocks of Lower Paleozoic age in the Anadarko Basin (Johnson and others, 1988 and Webster, 1980).

The Upper Ordovician Viola Group is a relatively widespread marine limestone sequence. Nodular chert is found at several stratigraphic intervals, and the entire unit is highly fossilferous (Johnson, 1991). The Viola Group grades upward from a dirty (organic and graptolitic-rich) shaly limestone into clean-washed skeletal limestones, indicating an upward decrease in water depth and a corresponding increase in the energy level of the system (Johnson and Cardott, 1992). The Viola is typically 182 to 275 m (600 to 900 ft) thick in the depocenter of the Anadarko Basin (Johnson, 1991).

The Upper Ordovician Sylvan Shale is a relatively extensive greenish-gray shale. Thickness values range from 90 to 120 m (300 to 400 ft) thick in the basin to 9 to 60 m (30-200 ft) thick on the shelf areas to the north. A deep water depositional environment is suggested by the presence of graptolites, chitinozoans, and well-developed laminations (Ham, 1969).

Consisting of a series of shallow-water carbonates, the Upper Ordovician-Devonian age Hunton Group lies above the Sylvan Shale. Named after the Hunton townsite by Taft in 1902, it was later subdivided into seven formations separated by numerous unconformities by Reeds (1910), Amsden (1957, 1960, 1975, 1988) and Shannon (1962). These are, in ascending order, the Keel, Cochrane, Clarita, Henryhouse, Bois d'Arc, Haragan, and Frisco. The Keel, Cochrane, and Clarita are further grouped into the Chimneyhill Subgroup.

Characterized by oolites and abundant fossils, the Keel Formation was deposited in the high energy region of an epieric sea. Oolites typically formed shoals in the shallow subtidal-intertidal waters where the Keel was deposited. The Keel covers hundreds of square miles as a thin oolite blanket, formed by the shoreward migration of the oolitic shoals (Manni, 1985).

The Cochrane Formation was deposited atop the Keel following a period of nondeposition. The Cochrane is believed to have been deposited on a ridge-and-swale topography on a carbonate ramp with a very gentle slope.

The Clarita Formation is divided into a lower Prices Falls member, which is a thin, continuous shale or marl bed, and an upper Fitzhugh Member, which primarily consists of fossilferous mudstones and wackestones (Barrick and others, 1990).

The Henryhouse-Haragan and Bois d'Arc intervals were deposited over much of Oklahoma by a shallow, low energy epieric sea (Adler, 1971; Feinstein, 1981; Al-Shaieb and others, 1993). Several facies are present, and transitions between the facies are generally gradational and in some instances quite subtle. Periodic transgressions and regressions resulted in migration of facies.

The Devonian Frisco Formation was deposited on an unconformity surface in relatively stable, subtidal conditions. The eroded paleotopography was condusive to the development of crinoidal bioherms in the Frisco interval. Frisco mound facies include a micritic-mound facies, a bioclastic intermound facies, and a bioclastic capping facies (Medlock, 1982).

Unconformably above the Hunton lies the Devonian Woodford Shale. It is a dark-gray to black fissile shale which contains chert and siliceous shale. Anaerobic to dysaerobic conditions dominated during deposition of the Woodford, repressing nearly all benthic organisms and favoring the preservation of organic matter. The Woodford is found throughout much of the Anadarko Basin with thickness values ranging from 60 to 275 m (200 to 900 ft) in the aulacogen, to 15 to 30 m (50 to 100 ft) on the shelf areas (Johnson and Cardott, 1992).

Mississippian sediments consist largely of shallow marine limestones, cherty limestones, and shales (Craig, Connor, and others, 1979; Frezon and Jordon, 1979, Johnson and others, 1988). A change in environment, from the euxinic seas which deposited the Woodford Shale to well-oxygenated, marine waters, resulted in the deposition of both fossilferous and oolitic limestones. These limestones are often interbedded with shale and siltstone. Pre-Chesterian strata consist primarily of cherty limestones and dolomites. Chert, which constitutes 10-30% of the rock, is assumed to replace carbonate (Johnson, 1989).

Chesterian strata mark a time in which the seas began to withdraw from the Mid-Continent. This regression produced the Springer Formation. The Springer consists mainly of shale, but does include several thick, interbedded sandstones. At the end of the Chesterian, the Mid-Continent emerged and left Upper Mississippian carbonates exposed in the Anadarko Basin (Rascoe and Adler, 1983).

Morrowan strata in the Anadarko Basin represent a period of overall marine transgression into the Mid-Continent and onlap the surface of eroded Mississippian rocks. Morrowan sediments are mainly shales with discontinuous and erratic sandstones, conglomerates, and limestones that form a thick wedge against the Wichita Uplift and thin onto the shelf. A paleotopographic map of the Morrow reveals a sand source to the west-northwest of the Texas and Oklahoma Panhandles and a second source to the north-

northeast (Figure 7). By the end of the Morrowan, the major source area shifted to the southwest and the rapidly rising Amarillo-Wichita Uplift.

The Morrowan Stage is customarily divided into upper and lower units. The lower Morrow is a sequence of marine sands, shales, limestones, and sandy limestones, deposited as Morrowan seas slowly transgressed from southeast to northwest across the Mississippian unconformity surface (Shelby, 1980). These deposits can be classified as tidal ridge/shoal complexes, offshore bars, tidal flats, and transgressive deposits (Walker, 1986). The end of this sequence was marked by deposition of a widespread argillaceous and arenaceous limestone unit, known as the "Squaw Belly" or "Indian Belly Swell" owing to its characteristic electric log signature (Shelby, 1980).

The upper Morrowan Stage is defined as all strata between the top of the "Squaw Belly limestone" and the base of the Atokan "Thirteen Finger limestone". The upper Morrow is composed of alternating sands, chert conglomerates, and marine shales (Johnson, 1989). The sandstone units were generally deposited by deltaic processes sourced to the north-northeast and west-northwest. North of the study area, upper Morrow strata are shale-dominated but contain thin chert-conglomerate and chert-sandstone reservoirs. The conglomerate-to-shale ratio increases southward, and the upper Morrowan becomes a conglomerate-dominated sequence in the vicinity of the Wichita frontal fault zone (Al-Shaieb and others, 1993e). These conglomerates are confined to a relatively small area in the eastern Texas Panhandle and western Oklahoma (Figure 8). The upper Morrowan chert conglomerate units have been interpreted as fan-delta complexes (Alberta, 1987) and coastal alluvial fans (Johnson, 1989). Upper Morrowan

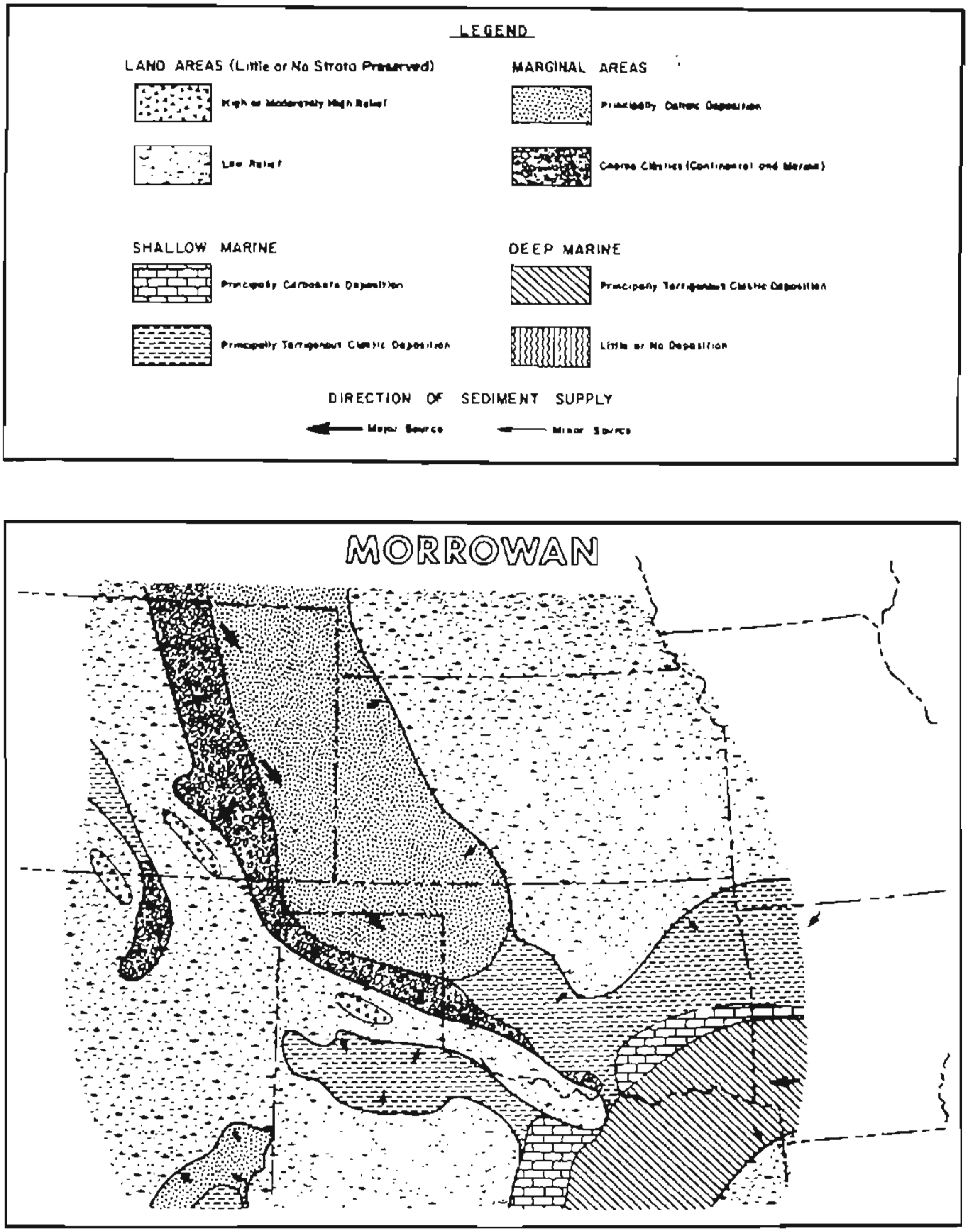


Figure 7. Generalized paleogeography and paleoenvironments of the Morrowan after Moore, 1979)

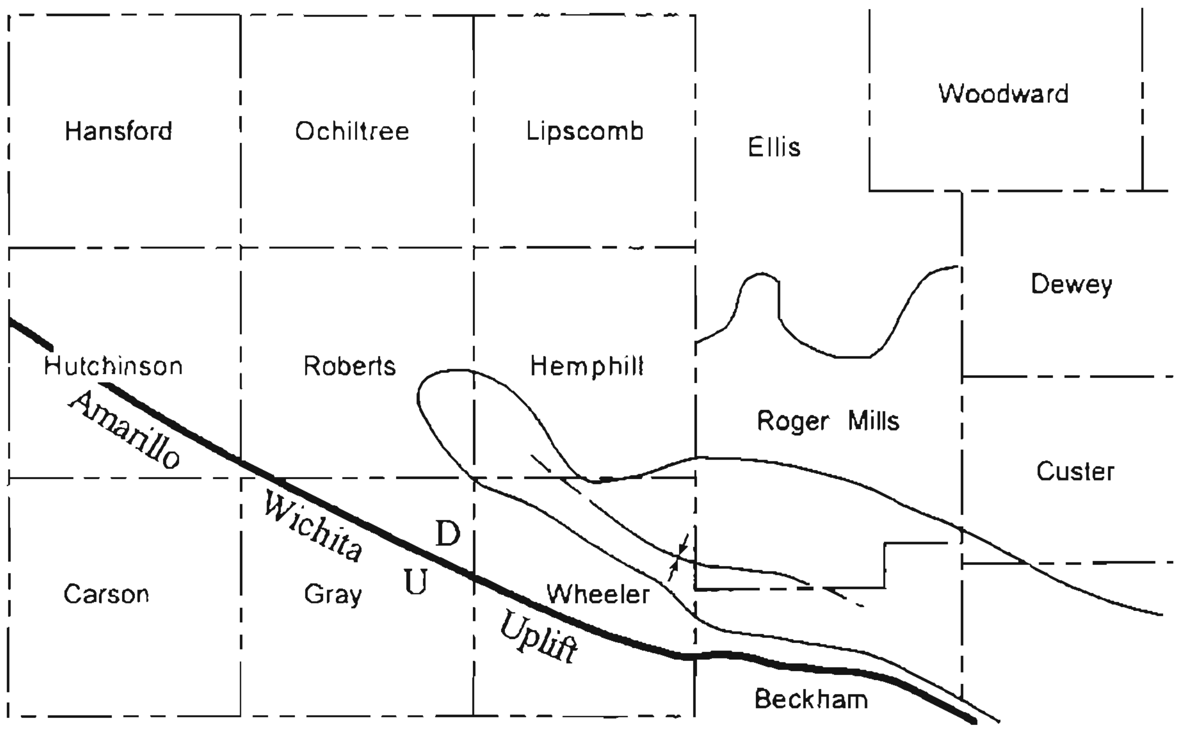


Figure 8. Limits of the upper Morrow chert conglomerate in the eastern Texas Panhandle and western Oklahoma (after Shelby, 1980).

conglomerates contain an abundance of detrital chert, ranging from sandstone to cobble-sized sized fragments. The source of these fragments was the chert-rich Mississippian rocks exposed on the rising Wichita Mountains to the south (Al-Shaieb and others, 1993e).

During Atokan time, the Amarillo-Wichita Uplift was the major source of sediments flowing into the Anadarko Basin. Termed the "Thirteen Finger limestone", a southward-thickening series of marine shales, sandstones, and limestones was deposited over most of the deep basin (Johnson, 1989). These sediments are commonly 15 to 60 m (50 to 200 ft) thick in the north and west. Toward the south, Atokan limestones and shales grade into a thick sequence of shale, and then to a massive clastic wedge composed of igneous and carbonate rock fragments (Johnson, 1989).

Thick dolomites of the Cambrian-Ordovician Arbuckle Group (Arbuckle dolomite) were exposed on the uplift, and a large amount of detrital "dolomite wash" was shed into the southwestern basin. Restricted exposures of Proterozoic granite contributed minor amounts of siliciclastic material to the dolomite wash deposit (Lyday, 1985). In some areas, the thickness of the Atokan clastic wedge exceeds 1220 m (4000 ft) (Johnson, 1989).

Desmoinesian sediments reflect a marine transgression over the central Oklahoma arch and the northern shelf area, extending into central Kansas. Periodic regressions were marked by deltaic deposition (Alberta, 1987). Desmoinesian strata in the northern Anadarko Basin include cyclic marine limestones and shales. Near the southern margin of the basin, marine sediments give way to "granite wash" eroded from the Wichita Mountains (Johnson, 1989).

From the Desmoinesian through the Early Permian, the Proterozoic/Cambrian granite core was exposed, and a tremendous amount of conglomeritic material ("granite wash") was transported into the basin. Uplift, erosion, and deposition throughout the Pennsylvanian and Early Permian resulted in more than 3960 m (13,000 ft) of synorogenic detritus with an inverted vertical age sequence. That is, detritus of older material is continually superposed upon detritus of younger material (Lyday, 1985). Differential uplift and/or erosion resulted in an intermingling of different-aged units.

Shales and sandstones, with minor carbonate units, characterize the Missourian Stage in much of the Anadarko Basin. Thick arkosic and carbonate "washes" eroded off the Wichita-Amarillo Uplift form a thick wedge of sediments to the south.

The Virgilian rocks consist of deltaic clastic wedges alternating with shallow marine shelf carbonates. These strata interfinger with a thick interval of "granite wash" along the front of the Wichita Uplift (Johnson, 1989). The Virgilian Stage ranges from 150 to 450 m (500 to 1500 ft) thick in the northern and western parts of the basin to greater than 1370 m (4500 ft) in the southeast (Johnson, 1989).

The Permian represents the final filling of the Anadarko Basin with carbonates, red beds, and evaporites. The Wolfcampian includes a lower transgressive unit of limestone and shale, with an upper regressive unit of red shale. Leonardian and Guadalupian rocks include alternating red beds and evaporites. By the end of the Permian, the Wichita Uplift had ended as had the transgression of Paleozoic seas into the Mid-Continent.

CHAPTER IV

PREVIOUS INVESTIGATIONS

Hydrostatic Pressure

A normal hydrostatic pressure gradient is defined as the pressure generated by a continuous column of fluid extending to the surface. The fluid column must be static, exhibiting no lateral movement. As a result, the maximum pressure gradient is vertical and a function of the gravitational weight of the overlying fluid column (Dahlburg, 1995). Because salinity in basins increases with depth, the petroleum industry typically uses a saline water column to determine the pressure gradient. The average gradient for a Gulf Coast basin brine with 100,000 ppm total dissolved solids (TDS) is 0.465 psi/ft (Stuart, 1970; Bradley, 1975). This value is accepted as the normal hydrostatic gradient.

Overpressure

Overpressure (geopressure) is common in subsurface rocks. A pore fluid is overpressured if its pressure exceeds that of the hydrostatic gradient at a specific depth (Osborne and Swarbrick, 1997). Bradley (1975) proposed that overpressuring requires a seal which prevents the pressure from equalizing with the hydrostatic pressure regime over geologic time.

Subsurface overpressuring is a worldwide phenomenon with numerous implications for the oil and gas industry. Overpressure areas affect both the trapping and recovery of hydrocarbons. Abnormally high formation pressures can present a serious hazard to drilling. The study of overpressure areas, therefore, plays a vital role in petroleum geology and basin analysis. It is a essential factor in the understanding of basin-wide fluid migration and the resultant accumulation of hydrocarbons (Luo and others, 1994).

Abnormal pressures have been studied by numerous researchers over the last sixty years. Cannon and Craze (1938) first discussed the occurrence of abnormal pressure in the Gulf Coast area. George Dickinson's 1953 study of anomalous pressure in the Gulf Coast is often credited with initiating widespread interest in abnormal formation pressures. Since then, interest in anomalous pressure has grown, and numerous articles have been written on the subject.

A review of the pertinent literature reveals several mechanisms of overpressure generation. While many mechanisms have been proposed to explain the phenomena of overpressuring, nonequilibrium compaction and hydrocarbon generation are the two most popular theories.

Many authors (Dickinson, 1953; Hubbert and Rubey, 1959; Rubey and Hubbert, 1959; Dickey, 1976; Fertl, 1976; Chapman, 1980; Plumley, 1980; Pickering and Indelicata, 1985; Bethke and others, 1988; Sahay and Fertl, 1988; Gretener, 1990) believe nonequilibrium (disequilibrium) compaction to be a feasible mechanism of overpressuring. As vertical loading of sediment increases during burial, rocks tend to compact, reducing the pore volume and forcing out the formation fluids. Under conditions of slow burial, normal sediment compaction occurs and equilibrium is maintained between overburden stress and reducing pore volume (Osborne and Swarbrick, 1997). During rapid burial, however, the expulsion of fluids cannot keep pace with subsidence. As burial continues, the pore fluid pressure rises above hydrostatic values in response to the continued increase in overburden (vertical force).

Nonequilibrium compaction typically occurs in thick, low permeable sediments during continuous rapid burial. Overpressure in adjacent, more permeable reservoir rocks may be generated through the stratigraphic isolation of the reservoir within a finer grained, low permeability section or by lateral permeability reduction such as a faulting (Osborne and Swarbrick, 1997).

Tectonic compression creates overpressure in a manner similar to nonequilibrium compaction. Unlike nonequilibrium compaction, however, the compaction-inducing forces involved in tectonic compression are horizontal. These compressive forces act on zones of low porosity and permeability causing pore pressure to increase (Hubbert and Rubey, 1959; Fertl, 1976; Pickering and Indelicata, 1985; Sahay and Fertl, 1988). Overpressure buildup due to tectonic processes is often rapid. However, if large volumes of fluid escape up fault planes, the resulting decrease in pressure will be equally rapid (Osborne and Swarbrick, 1997).

Aquithermal pressuring occurs in a rock system that is perfectly sealed and maintains a constant volume as temperature increases (Osborne and Swarbrick, 1997). The increase in temperature with burial depth causes pore waters to expand at a greater rate than the expansion of the host rock. If the pore waters are prohibited from escaping by a flow barrier, such as a seal, pore pressure will increase. Aquithermal pressuring, was proposed by Barker (1972) and Barker and Horsfield (1982). Some authors (Chapman, 1972, 1980; Daines, 1982) dismiss aquithermal pressuring because it requires a perfect seal-- a geologic rarity. Even slight leakage across the seal would instantly dissipate any overpressuring. Other authors (Barker, 1972; Magara, 1975; Plumley, 1980; Gretener, 1990) reason that in abnormally pressured, normally compacted rocks, aquithermal pressuring must exist. However, with the possible exception of thick salt beds, no *perfect* seals have been documented.

The transformation of smectite to illite at temperatures greater than 221°F can generate minor overpressuring. The interlayer water molecules are arranged in a denser packing arrangement than those of ordinary water. During the transformation, interlayer water is expelled to become pore water. If the rock is sealed, the addition of this released water coupled with the thermal expansion of the pore fluids will increase the formation pressure to abnormal levels (Fertl, 1976; Berg and Habeck, 1982; Pickering and Indelicata, 1985; Sahay and Fertl, 1988, Freed and Peacor, 1989).

In isolated compartments, the generation of hydrocarbons may result in overpressuring. A significant volume increase occurs as oil is thermally cracked into methane (Hunt, 1990). Furthermore, the difference in density between hydrocarbons, especially natural gas, and water can create abnormal pressure at the tops of hydrocarbon accumulations (Hubbert and Rubey, 1959). The longer the hydrocarbon column, and the greater the density contrast between the hydrocarbon and the surrounding water, the greater the overpressuring.

The isolation and uplift of deep, gas-filled compartments can also result in the generation of overpressure. As the temperature within an isolated, gas-filled compartment decreases in response to uplift and removal of overburden, volumetric contraction of the gas results in pressure within the compartment decreasing at a rate lower than the hydrostatic gradient, such that the compartment becomes overpressured relative to adjacent hydrostatically pressured strata (Barker, 1979).

Osmosis is the mass transfer of water through a semipermeable membrane from low salt concentration to high concentration. If the pore water within an isolated zone is saltier than the pore water surrounding the zone, then osmotic flow will be inward and the pore pressure within the zone will increase (Martinsen, 1994). Water may also flow from a high-pressure, high-salinity zone to a lower-pressure, lower-salinity zone (Fertl, 1976; Pickering and Indelicata, 1985; Sahay and Fertl, 1988). This phenomena, termed reverse osmosis, results in increased pressure in the low-salinity zone as water flows into it from a highly overpressured zone. As the movement of water across a membrane is a requirement for osmosis, neither mechanism applies to the creation of overpressure in effectively sealed compartments.

Hydraulic Systems

A layered arrangement of superimposed hydraulic systems exists in most deep sedimentary basins (Figure 9). The shallower hydraulic systems are basin-wide in extent and normally pressured. Fluids are free to migrate throughout the system. Such systems typically extend from the surface down to roughly 3050 m (10,000 ft) in normal geothermal gradient basins and to slightly greater depths in cool basins (Powley, 1987)

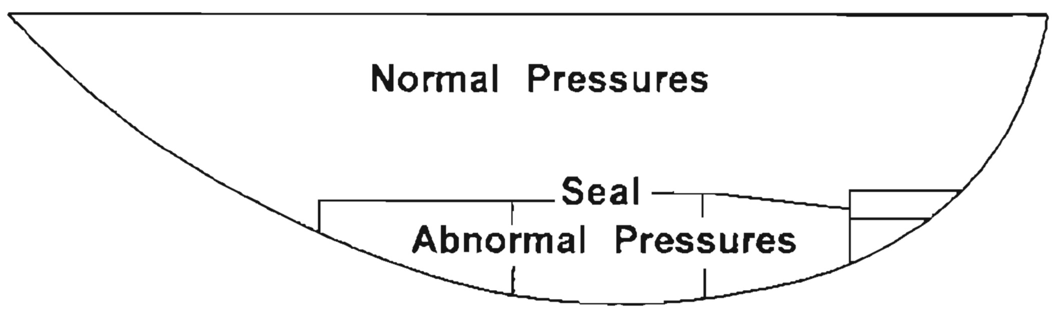


Figure 9. Layered arrangement of superimposed hydraulic systems. The shallow hydraulic system is basin-wide in extent and exhibit normal pressures. The deeper system is overpressured and consists of numerous fluid compartments which are sealed off from each other and the surrounding rock (after Powley, 1987).

The deeper (below 3050 m or 10,000 ft) hydraulic systems are typically not basin-wide in extent and exhibit abnormal pressure. They commonly consist of a layer of individual fluid compartments which are sealed off from each other and the overlying system. In some basins, including the Anadarko Basin, there is an even deeper, normally pressured noncompartmented section (Figure 10). The compartmented layer is thought to be the sequence of rock which underwent the most rapid deposition (Powley, 1987).

Pressure Compartments

Pressure compartments are present in sedimentary basins throughout the world. They are mainly recognized by their abnormal fluid pressures but may be indicated by differing brine and hydrocarbon chemistries, mineralogic differences, electrical resistivities, sonic velocities, shale densities, mud weight requirements, and changes in drilling rate (Bradley,1975; Powley, 1987, 1989).

The idea of pressure compartments in sedimentary basins was introduced by Powley and Bradley (1975, 1987, 1989). Their research at Amoco led to the notion that the deeper (below 3050 m or 10,000 ft) parts of a sedimentary basin are often divided into a boxwork of domains (compartments). These compartments are hydrologically isolated from their surroundings (Bradley, 1975; Powley, 1987, 1989).

An idealized compartment is shown in Figure 11. Its hydrologic isolation is maintained by an encasing shell of low permeability rock. The interior of the compartment is of relatively good permeability, so there is good hydraulic communication within the compartment itself (Ortoleva and others, 1995).

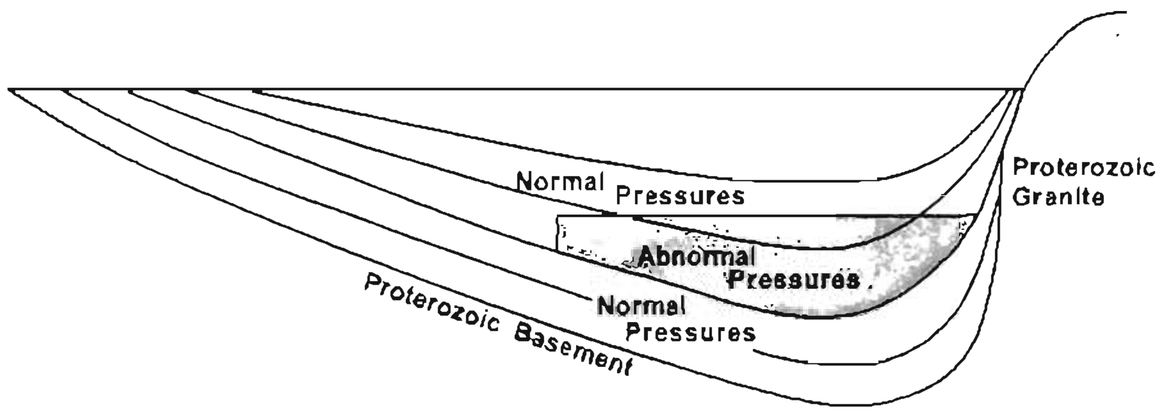


Figure 10. Basin in which an overpressured compartment is bounded above and below by normally pressured compartments (after Powley, 1987).

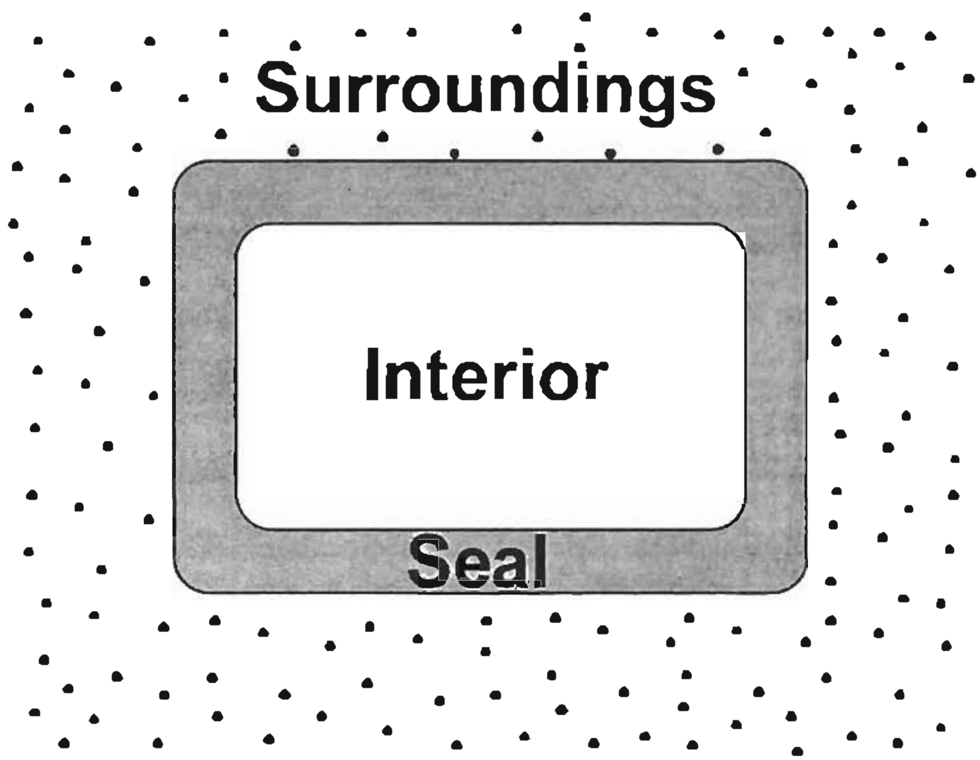


Figure 11. Idealized compartment of Powley and Bradley showing an interior of relatively good hydraulic connectivity isolated from its surroundings by a low permeability seal (after Ortoleva and others, 1995).

It should be noted that no domain of rock can exist in perfect hydraulic isolation forever. All rocks have some residual permeability. The Powley and Bradley concept of compartmentation centers, therefore, around the notion that compartments can be sealed off for appreciable durations of geologic time (a million years or more).

Mega-Compartment Complex

Introduced by Al-Shaieb (1991), a mega-compartment complex (MCC) is a basin-scale overpressured compartment enclosed by top, basal, and lateral seals. A mega-compartment within a basin is easily recognized on pressure depth profiles by the departure from the normal hydrostatic pressure of 0.465 psi/ft (10.52 kPa/m) (Figures 12 and 13). The interior of the compartment may be subdivided into an array of smaller compartments, the entire assemblage being denoted as a mega-compartment complex. A mega-compartment may involve several levels of internal compartment nesting (Ortoleva and others, 1995). These nested compartments can be multiple, district, or field-sized configurations (Level 2) or single fields or reservoirs (Level 3) nested within Level 2 compartments (Figure 14).

In the Anadarko Basin, the MCC is approximately 150 miles long and 70 miles wide, and possesses a maximum thickness of 4875 m (16,000 ft). Pressure data reveal that the top of the MCC is located between 2280 and 3050 m (7,500 and 10,000 ft) below the surface (Al-Shaieb and others, 1994b). The top is shallower in the northern regions of the basin and dips gently toward the basin axis in western Oklahoma. The MCC contains overpressured strata ranging in age from Upper Devonian to Upper Pennsylvanian (Figure 15).

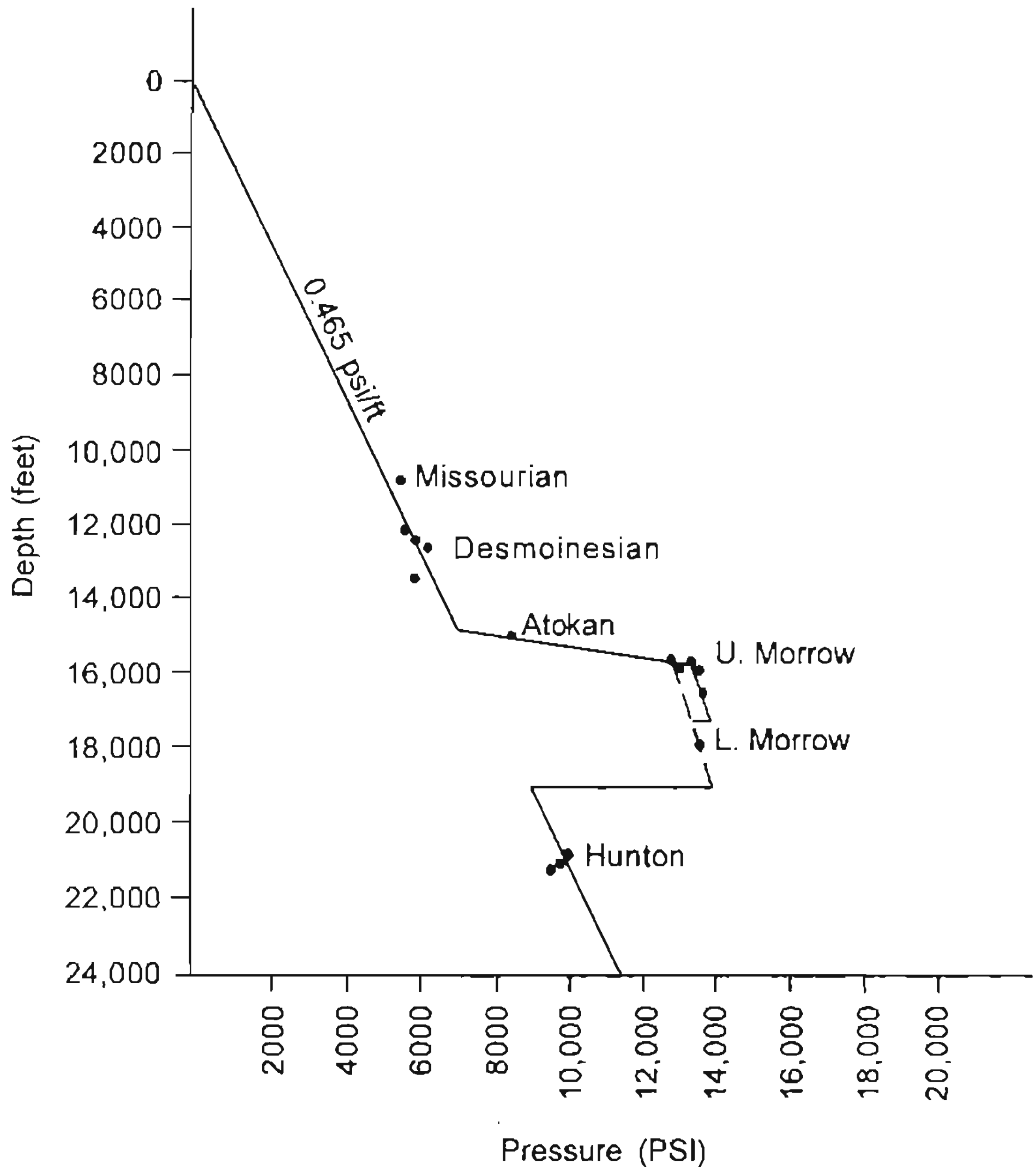


Figure 12. Pressure-depth profile from eastern Wheeler County, Texas. The drastic change in slope exhibited by the Morrowan interval indicates a sharp increase in the pressure gradient (after Al-Shaieb and others, 1994b).

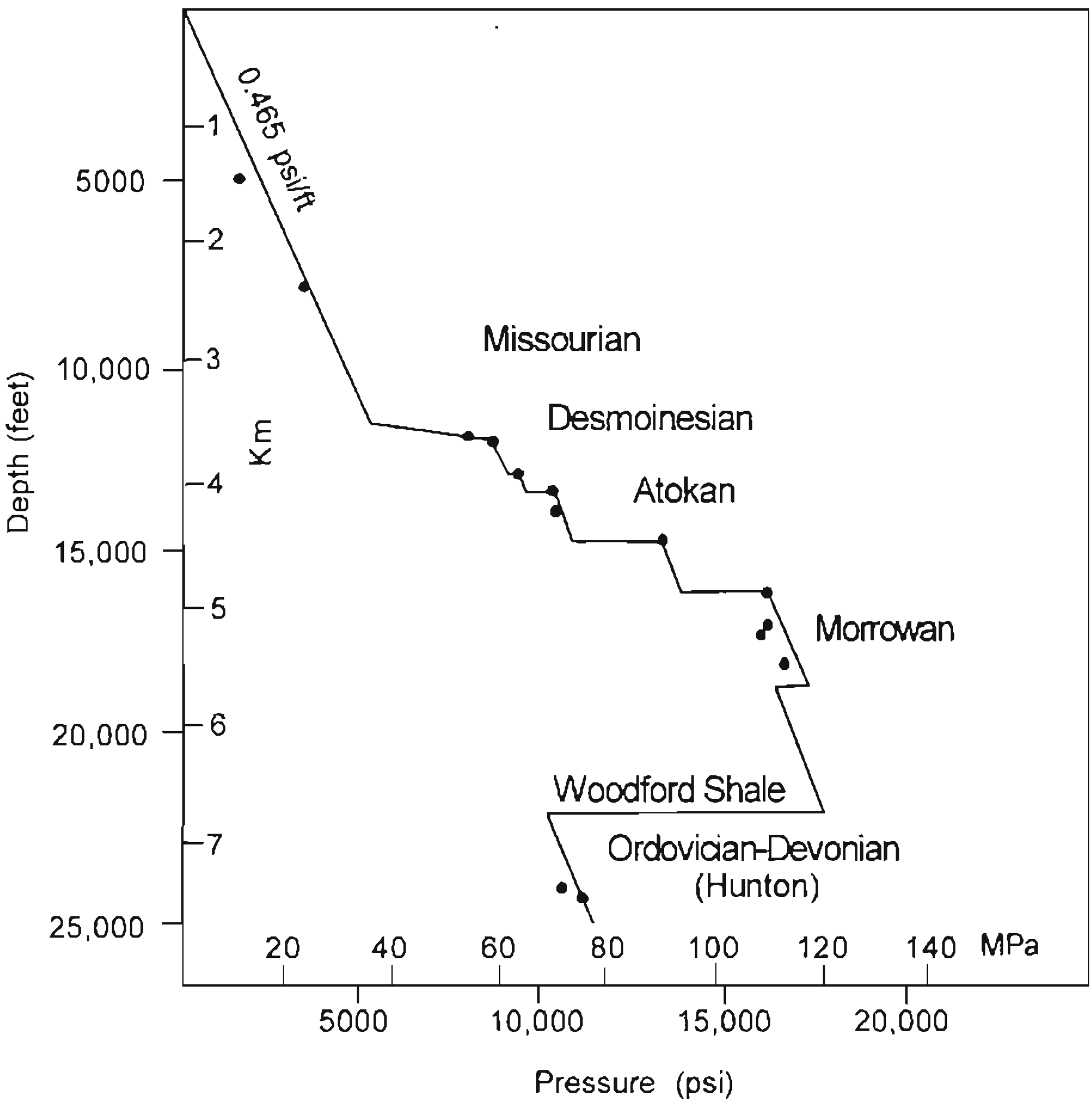


Figure 13. Pressure-depth profile from western Roger Mills County, Oklahoma. Overpressuring begins in the lower Missourian and continues until the Woodford Shale (after Al-Shaieb and others, 1994b).

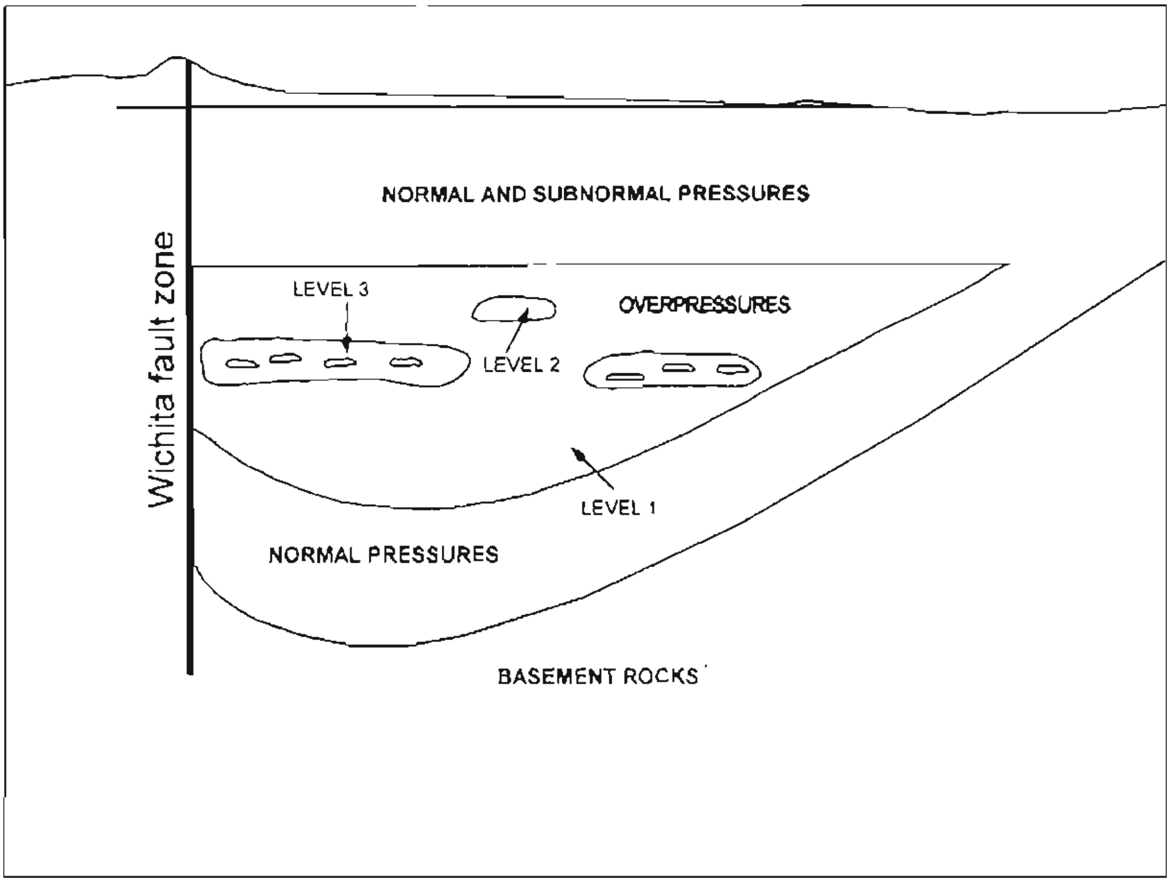


Figure 14. Schematic illustration depicting the three levels of compartmentation within the Anadarko Basin.

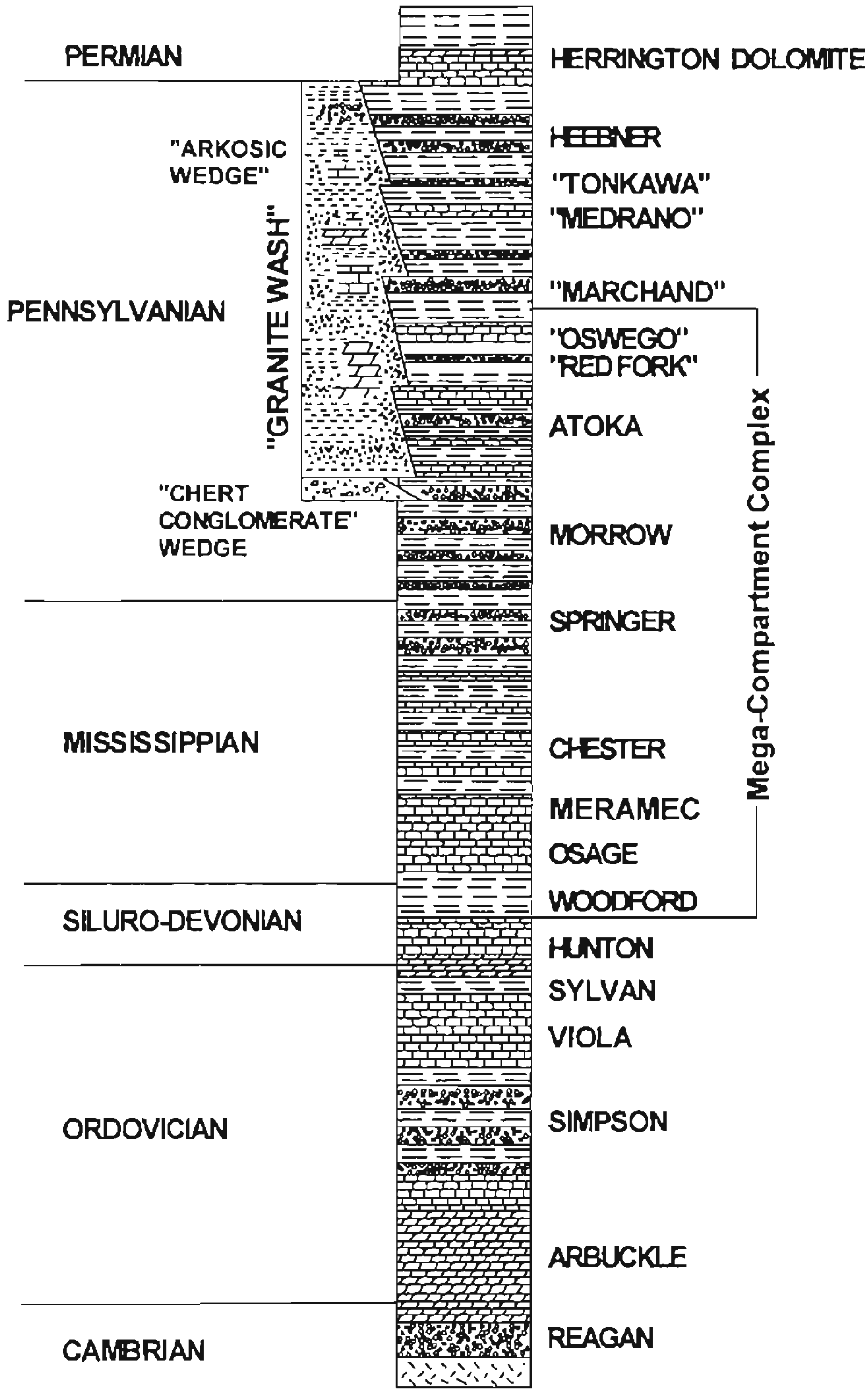


Figure 15. Generalized stratigraphic column of the Anadarko Basin showing the intervals contained within the MCC (modified after Al-Shaieb and others, 1994b)

CHAPTER V

GENESIS AND CHARACTERIZATION OF VERTICAL SEALS

Introduction

The understanding of vertical sealing mechanisms is crucial to the assessment of reservoir compartmentalization. Abnormal formation pressure cannot exist for appreciable durations of time without a seal. In the absence of a seal, the pressure will equilibrate with the hydrostatic pressure regime (Bradley, 1975). Likewise, the very definition of a pressure compartment requires effective sealing in three dimensions-- there must be vertical as well as horizontal seals. Many vertical seals are fault related. This implies that faults tend to promote some intrinsic mechanism of vertical seal genesis, but there is an underlying mechanism that does not require faulting (Ortoleva and others, 1995).

As seals are zones of low porosity/permeability, it follows that the processes which create seals are those which reduce the porosity/permeability in a given rock body. The reduction of porosity to form vertical seals is the result numerous mechano-chemical processes operating in deep sedimentary basins. The dynamics of the system is complicated not only because of the number of operating processes, but also because these processes are intimately related.

Vertical Sealing Mechanisms

According to the literature, there are numerous mechanisms for generating vertical seals. Some of these processes are based on the notion that the fault itself constitutes a lateral seal. Others depend on the interaction between the fault and its environment during basin evolution. A brief discussion of the various processes responsible for generating vertical seals follows.

Granulation

Granulation results in the production of fine grained particles that reduce porosity/permeability in the fault zone. Slight rotation and faint fracturing/cracking of grains represents the initial stage of granulation. The second stage is marked by a significant increase in rotation and the distinct crushing of grains into smaller, fine-grained fragments. Intense fracturing of grains is evident, and clays coat the grains and fill the open fractures. The final granulation stage is the complete replacement of the crushed grain by clay minerals (Engelder, 1974).

Gouge

Gouge reduces porosity/permeability in a manner similar to gouge. Wall rocks that are weak and incompetent respond in a plastic manner to faulting and are frequently converted to gouge along the fault contact. Gouge is a very fine grained clayey crushed rock. It may retain several pieces of resistant grains that did not completely succumb to the crushing processes. Gouge zones range anywhere from thin, whispy sections to large regions, several meters wide (Davis, 1984).

Ostwald Ripening

Ostwald ripening involves particle size reduction to very fine levels following motion along a fault (Figure 16). The elevated free energy of the fine-grained particles may result in their dissolution. In the absence of clay coatings, reprecipitation may occur locally. If, however, clay coatings are found in the same region as the fine-grained sediments, reprecipitation will occur in neighboring areas (Ortoleva and others, 1995).

Intergranular Pressure Solution

Intergranular pressure solution involves "the interpenetration of adjacent grains in contact under the influence of directed pressure and in the presence of interstitial solution" (Pittman and Lumsden, 1968). The silica dissolved at pressure solution contacts may precipitate as quartz cement on the unstressed regions of the grain from which it was dissolved. Alternately, the liberated silica may be removed from the site of dissolution by circulating pore fluids. Its fate depends largely on the chemical and hydraulic characteristics of the pore fluid (Houseknecht, 1984).

In their 1987 paper, Houseknecht and Hathon examined some of the geologic variables which influence intergranular pressure solution. A summary of their findings is presented in Table I. Of particular importance to this study is the fact that overpressuring tends to inhibit pressure solution by reducing the effective stress on grain contacts.

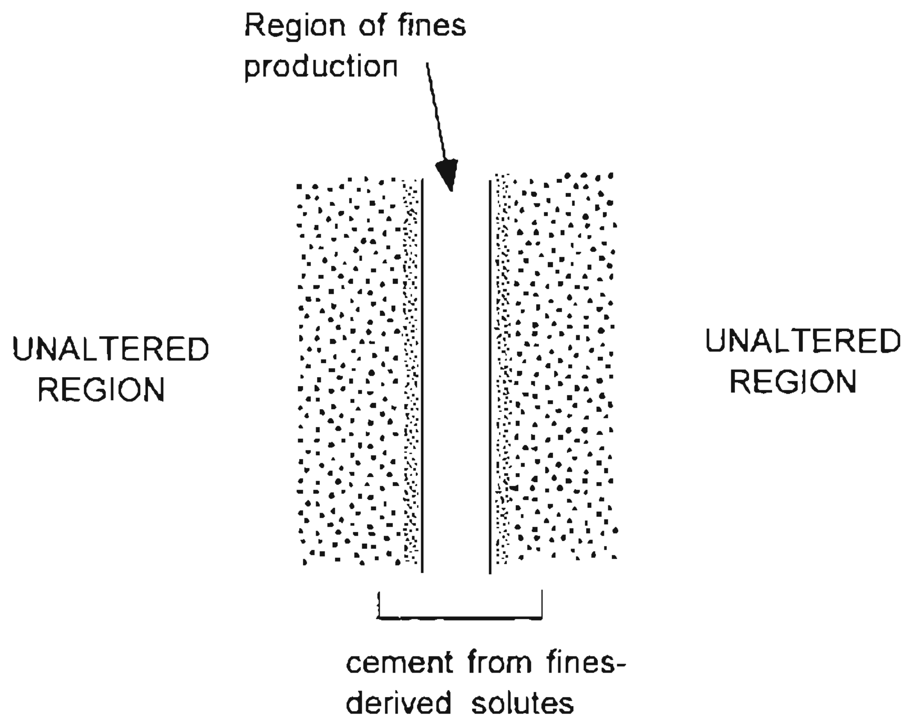


Figure 16. Grain size reduction and the production of fine-grained sediments in a fault zone can provide higher levels of dissolution solutes. Grain overgrowth, or nucleation, can cause the lowering of permeability both within and in the immediate vicinity of the fault (after Ortoleva and others, 1995).

Geologic Variable	Effect on Intergranular Pressure Solution (IPS)
Sorting	No significant effect in moderately-very well sorted sandstones. May inhibit IPS in poorly sorted sandstones
Framework Grain Composition	As mineralogical complexity increases, IPS is commonly inhibited.
Clay Content	Illite and smectite appear to promote IPS. Kaolonite and chlorite have no effect on IPS.
Presence of cements ppt. during shallow burial	Inhibits or eliminates IPS
Depth of Burial	Tendency for the amount of IPS to increase with depth of burial, but local geological variables exert influence.
Slow Shallow Burial	Generally decreases IPS
Rapid Shallow Burial	Generally increases IPS
Time	Increased time at a given pressure and temperature tends to increase IPS.
Temperature	Generally increases IPS
Fluid Flow	Generally increases IPS
Overpressure	Decreases IPS
Grain Size	In general, IPS increases with decreasing grain size. However, IPS is not confined to fine grained sediments.

Table I. Summary of the effects that geologic variables exert on intergranular pressure solution (IPS) (modified after Houseknecht and Hathon, 1987).

Preferential Fluid Flow

Contact of a body of rock with its environment can promote a reduction in the porosity-permeability at its boundary. If the pressure and/or temperature of the system are/is altered (i.e. near the fault zone), the conditions for precipitation are modified.

When a fault in hydraulic contact with normally-pressured strata breaches a pair of horizontal seals in an overpressured compartment, a fluid pressure gradient is created. The lowest pressure will be near the fault (Ortoleva and others, 1995).

Preferential flow results from the pressure differential that develops between subsiding overpressuring reservoirs and a fault that remains near hydrostatic due to recurring reactivation. Higher-pressured solute-rich fluids flow toward the near-normally pressured fault zone. As a result of the fluid influx and modified environment, cements are precipitated in the proximity of the fault, generating lateral seals within individual rock units (Al-Shaieb and others, 1993c) (Figure 17).

Augmented Compaction in the Fault Vicinity

Overpressure tends to preserve porosity and permeability by reducing the effective stress on grain contacts. Rocks adjacent to the fault, therefore, will compact more readily or undergo comminution if the pressure drop is significant (Ortoleva and others, 1995). Accelerated pressure solution through decreased fluid pressure may create a gradational vertical seal, as suggested in Figure 17.

The mechanism of augmented compaction proposes that stress-induced dissolution and reprecipitation are relatively greater in the lower-pressured rocks adjacent

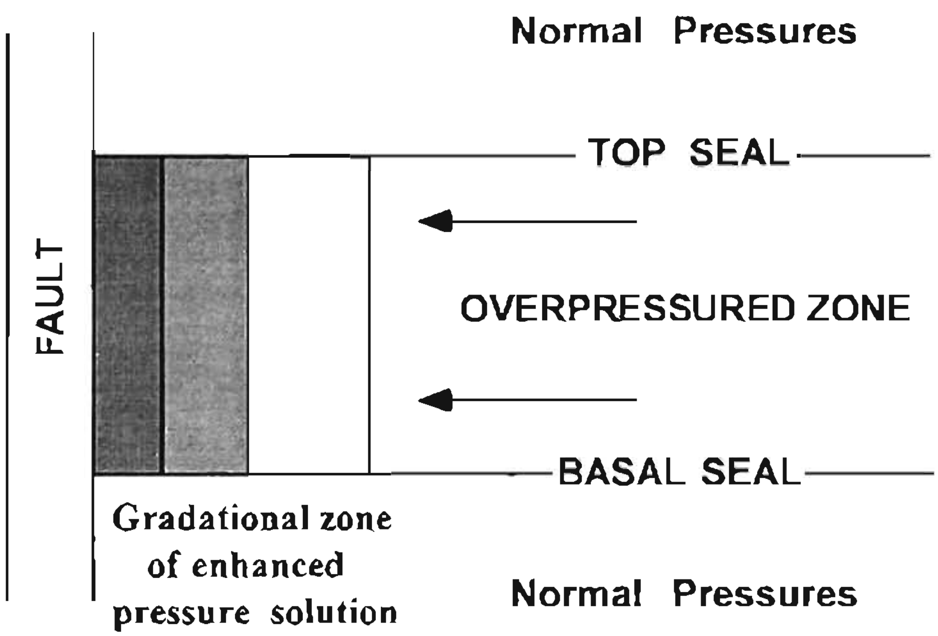


Figure 17. The fault imposes hydrostatic conditions at the left-hand end of the otherwise sealed, overpressured bed. Compaction is slowed by overpressuring away from the fault but is not arrested near the fault. Arrows indicate the fluid flow from high to low pressure (modified after Ortoleva and others, 1995).

to the fault. However, compaction is reduced as fluid pressure increases away from the fault zone, generating a gradational vertical seal.

Vertical Seal Development in the Western Anadarko Basin

A gradational lateral (vertical) seal has arisen in the western Anadarko Basin adjacent to the Wichita frontal fault zone. Examination of thin sections and cores suggests that preferential fluid flow and augmented compaction in the fault vicinity were the driving mechanisms behind seal formation.

The following chapters will present the petrographic and petrologic observations which led to the conclusion that the cemented interval along the frontal fault zone of the Wichita Mountains forms a low porosity fairway that functions as the southern lateral seal to the MCC.

CHAPTER VI

CHARACTERISTICS OF FAULT-ASSOCIATED RESERVOIR ROCKS

Introduction

Coarse clastic units within the overpressured domain are tightly cemented in the vicinity of the Wichita frontal fault zone. This cemented zone occurs in several stratigraphic intervals and extends vertically for thousands of meters. Overpressured chert pebble conglomerates and sandstones, carbonate pebble conglomerates and calcarenites, and granitic conglomerates and sandstones exhibit extensive cementation.

Fifty-six thin sections were examined under the petrographic microscope in order to interpret the depositional and diagenetic histories of the rock units adjacent to the frontal fault zone of the Wichita Mountains. Detrital and diagenetic constituents were identified, and their relative percentages were obtained through point counting. X-ray diffraction analysis was used to support the petrographic findings. Pore types, volumes, and geometry were determined, and from these observations, it was possible to characterize the units as either reservoirs or confining units (seals).

Fault-Associated Reservoirs Above the Overpressured Interval (MCC)

Adjacent to the frontal fault zone of the Wichita Mountains, normally pressured reservoirs above the MCC contain cements generated during normal burial, compaction, and maturation. However, they managed to escape the total porosity occlusion observed in the overpressured rocks, for there was no pressure differential to drive fluid migration.

Detrital Constituents

Quartz, feldspar, and granophyre rock fragments are the dominant detrital constituents in the granitic conglomerates and sandstones above the MCC. The amount of detrital quartz in the Shell Whitledge and Exxon Felton cores ranges from a low of 11% to a high of 50% (Figures 18 and 19). Syntaxial quartz overgrowths are found rimming the detrital grains.

Both potassium (orthoclase, microcline, and sanidine) and plagioclase feldspars are present. Untwinned orthoclase is the most abundant potassium feldspar, forming up to 35% of the total rock. Microcline, with its characteristic iron-grid twinning is found in minor amounts (less than 12% of the total). Plagioclase accounts for up to 31% of the total rock. It is readily identified by its albite twinning, and it exists in various stages of alteration/dissolution (Figure 19).

Granophyre grains are the most abundant rock fragment. Granophyre percentages in the Shell Whitledge and Exxon Felton cores range from 11 to 26% (Figures 18 and 19). The unstable granophyre grains are often highly dissolved, resulting in the generation of porosity. Microperthite, with its subparallel intergrowths of albite occurring as small veins in potassium feldspar, is a common feature (Figure 18).

Fossil fragments are found in the lower, marine interval of the Exxon Felton core. The dissolution of these fossil fragments resulted in the generation of calcite cement.

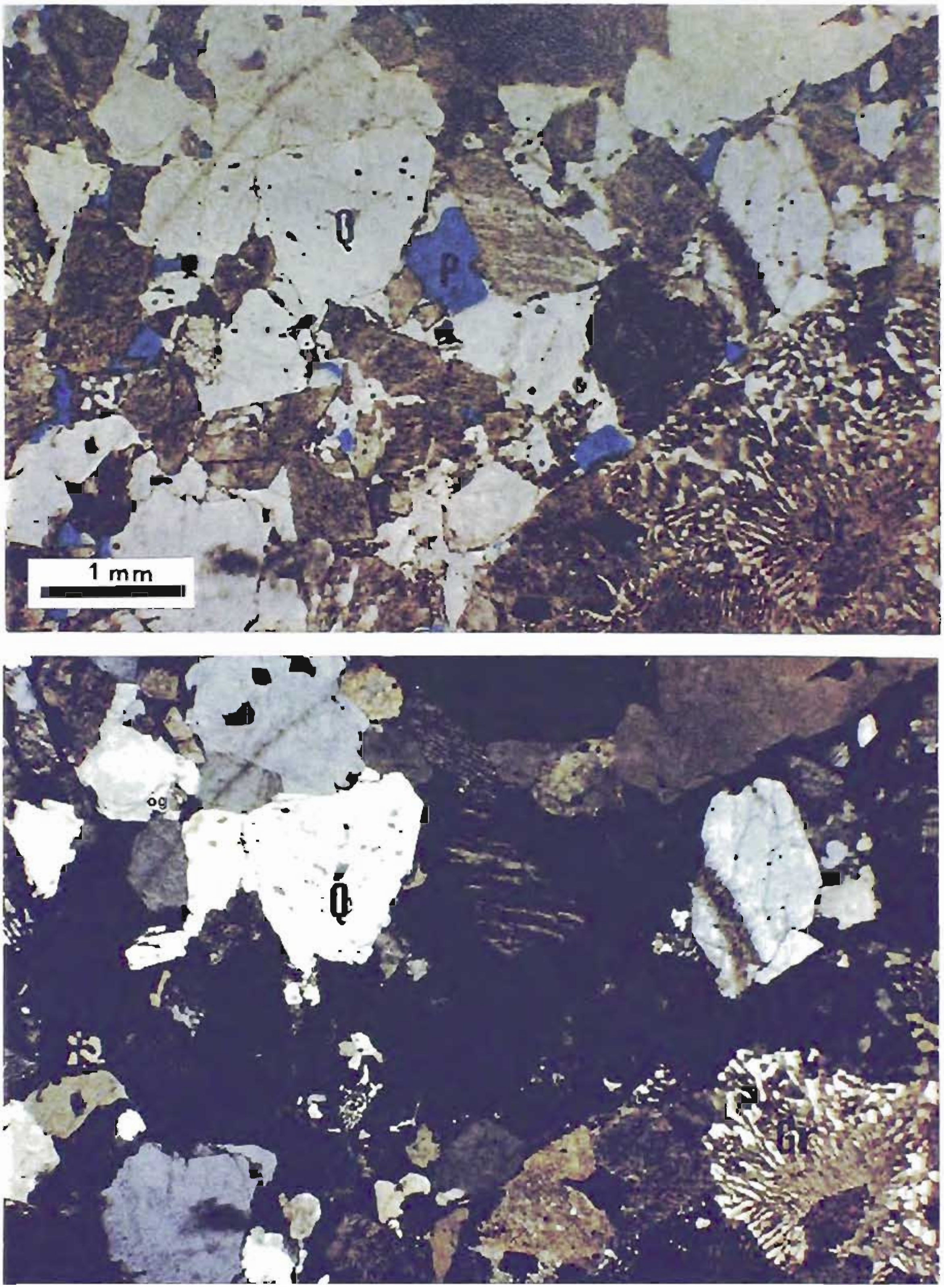


Figure 18. Microperthite (Mp), granophyre (Gr) and quartz (Q). Silica generated by compaction-induced dissolution is precipitated as quartz overgrowths (OG). Intergranular porosity (P) is evident. Shell Whitledge No. 1-8. Depth 8,542 feet. Top photo in PPL, bottom photo in XN (photo by J. Puckette).

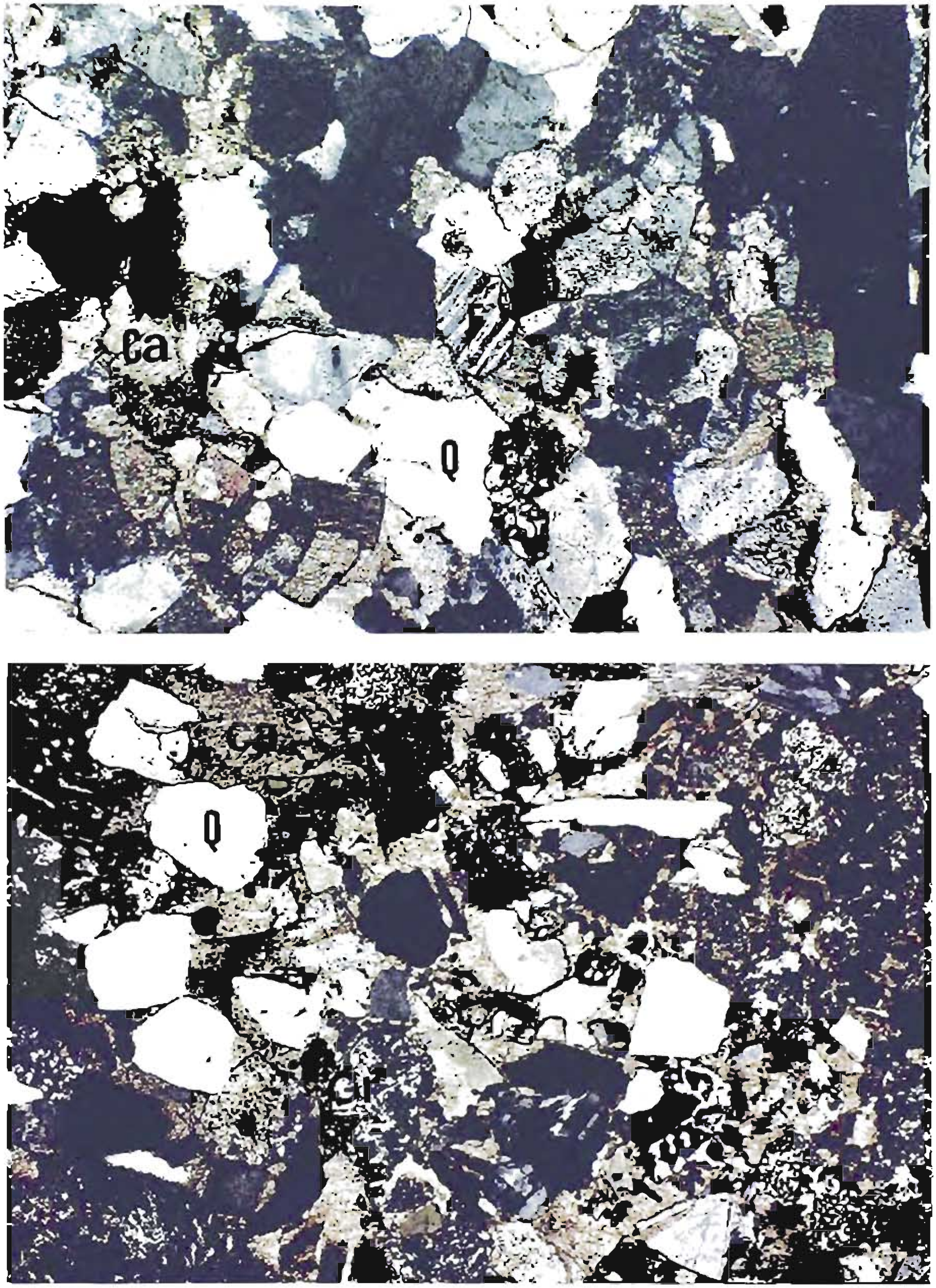


Figure 19. Quartz (Q), plagioclase feldspar (F), and granophyre (Gr) grains cemented by calcite (Ca). Top: Shell Whitledge No. 1-8. Depth 8505 feet. 100X, XN. Bottom: Exxon Felton No. 1-6. Depth 12,945 feet, 100X, XN.

A detrital clay/silt matrix occurs in some intervals. Larger grains "float" in the matrix, indicating that the clay/silt was introduced simultaneously. The matrix-rich zones are characterized by little or no porosity, as the presence of a primary matrix prevented fluids from flowing through the rock (Figure 20).

Diagenetic Imprints

Silica

A minor amount of stress-induced dissolution and precipitation occurred in the Shell Whitledge core, but significant porosity occlusion by multi-episodic cementation is lacking. The effects of silica diagenesis are more pronounced in the deeper Exxon Felton core. The sole manifestation of silica cementation occurs in the form of early syntaxial quartz overgrowths. These cements are readily recognized by their euhedral crystal faces (Figure 21). Pronounced dust rims separating the overgrowth from the detrital grain are rare. Quartz overgrowths in the normally pressured interval above the MCC partially occlude porosity and account for less than 4% of the total rock.

Carbonate

In the marine facies of the Exxon Felton core, very early micritic calcite is abundant (Figure 22). The dissolution of fossil fragments and micritic cements resulted in the subsequent precipitation of sparry calcite (Figure 23). Following precipitation of the sparry cement, the pore-water chemistry remained near saturation with regard to calcite, and quartz and granitic grains were partially replaced by additional calcite.

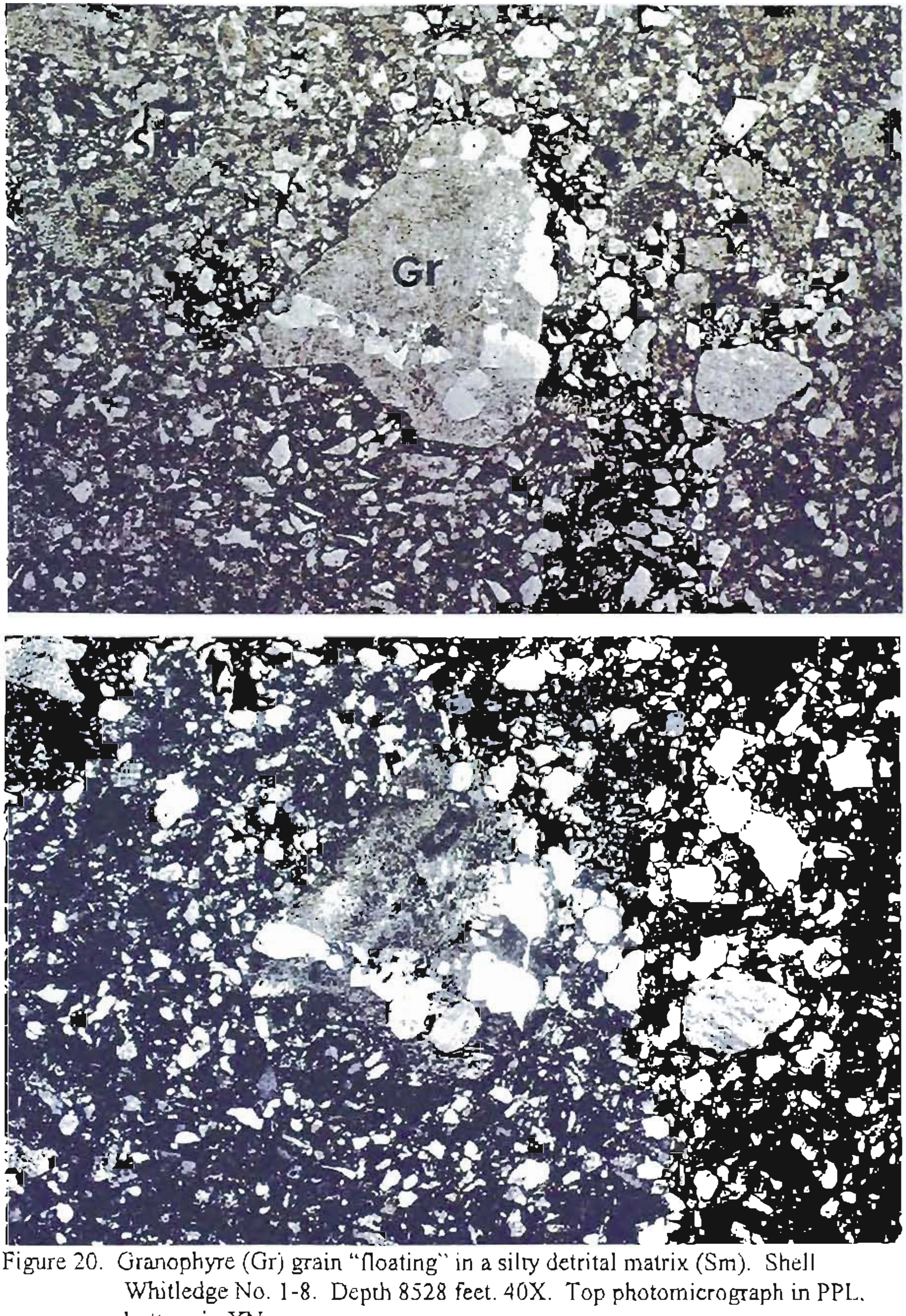


Figure 20. Granophyre (Gr) grain "floating" in a silty detrital matrix (Sm). Shell Whitledge No. 1-8. Depth 8528 feet. 40X. Top photomicrograph in PPL, bottom in XN.

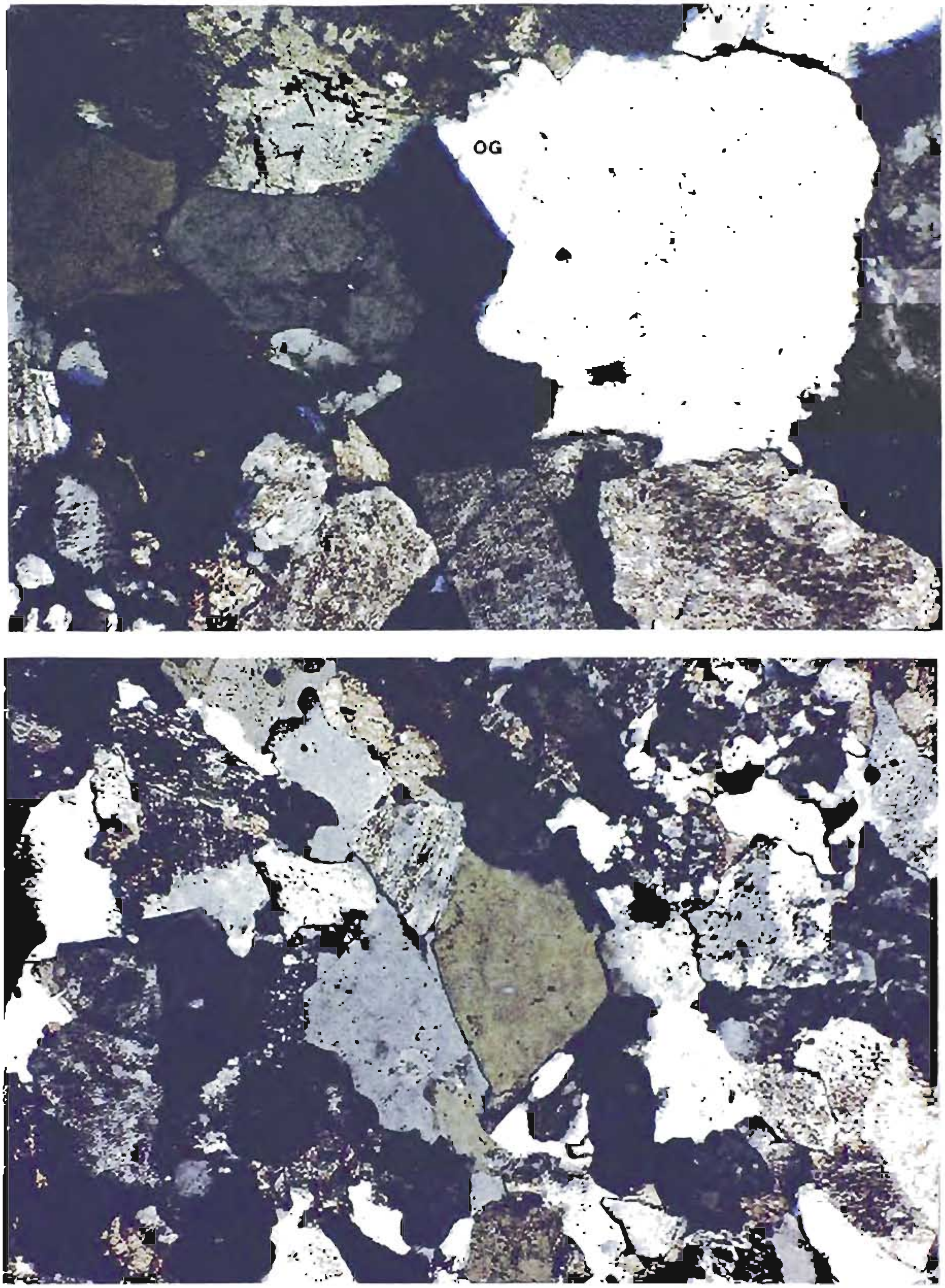


Figure 21. Euhedral quartz overgrowth (OG) rimming detrital quartz grains. Exxon Felton No. 1-6. Depths 12,929 (top) and 12,938 feet (bottom). 100X, XN.

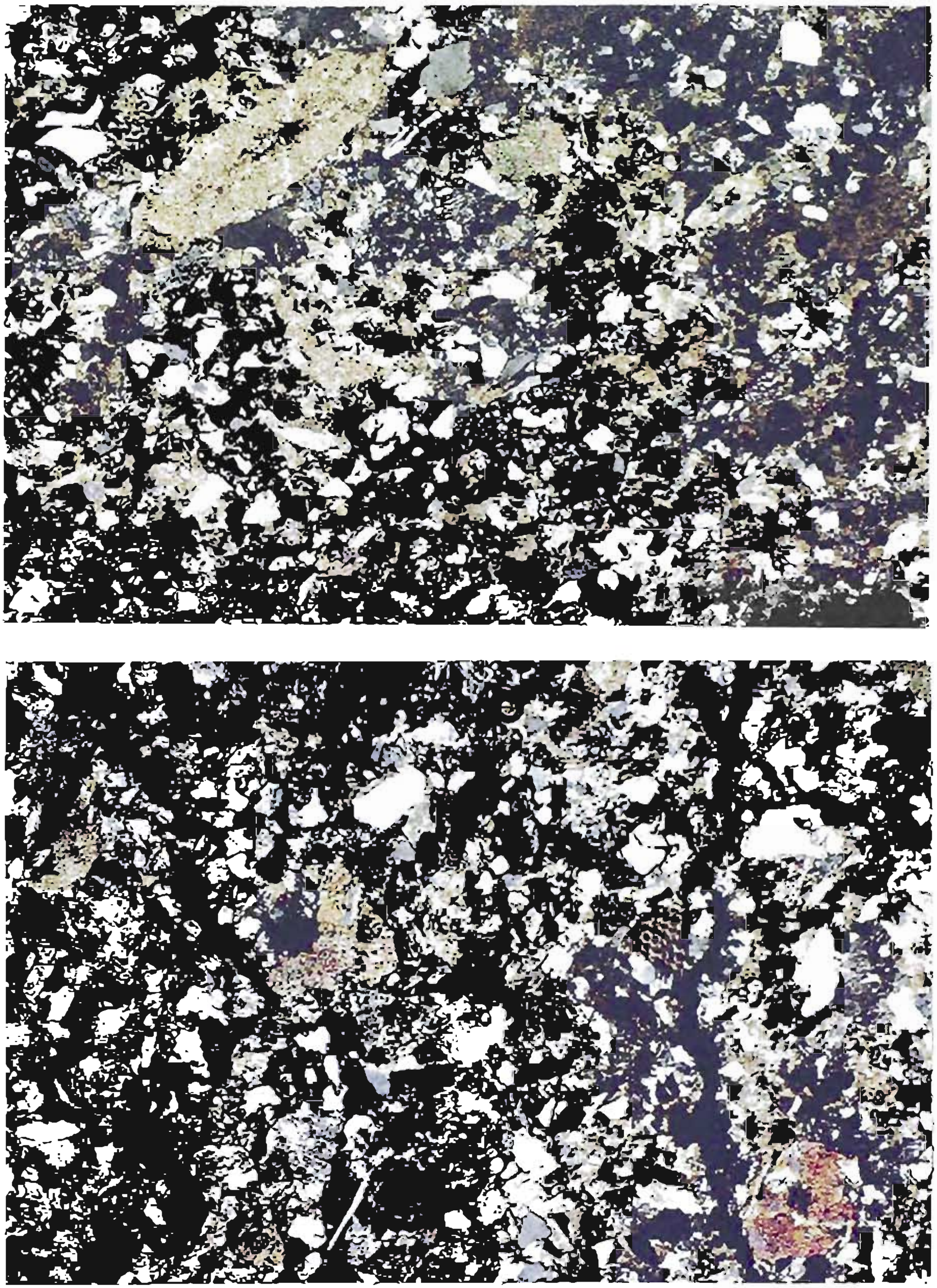


Figure 22. Marine facies containing fossil fragments and early micritic calcite. Exxon Felton No. 1-6. Depth 13,093 feet. XN, 100X.

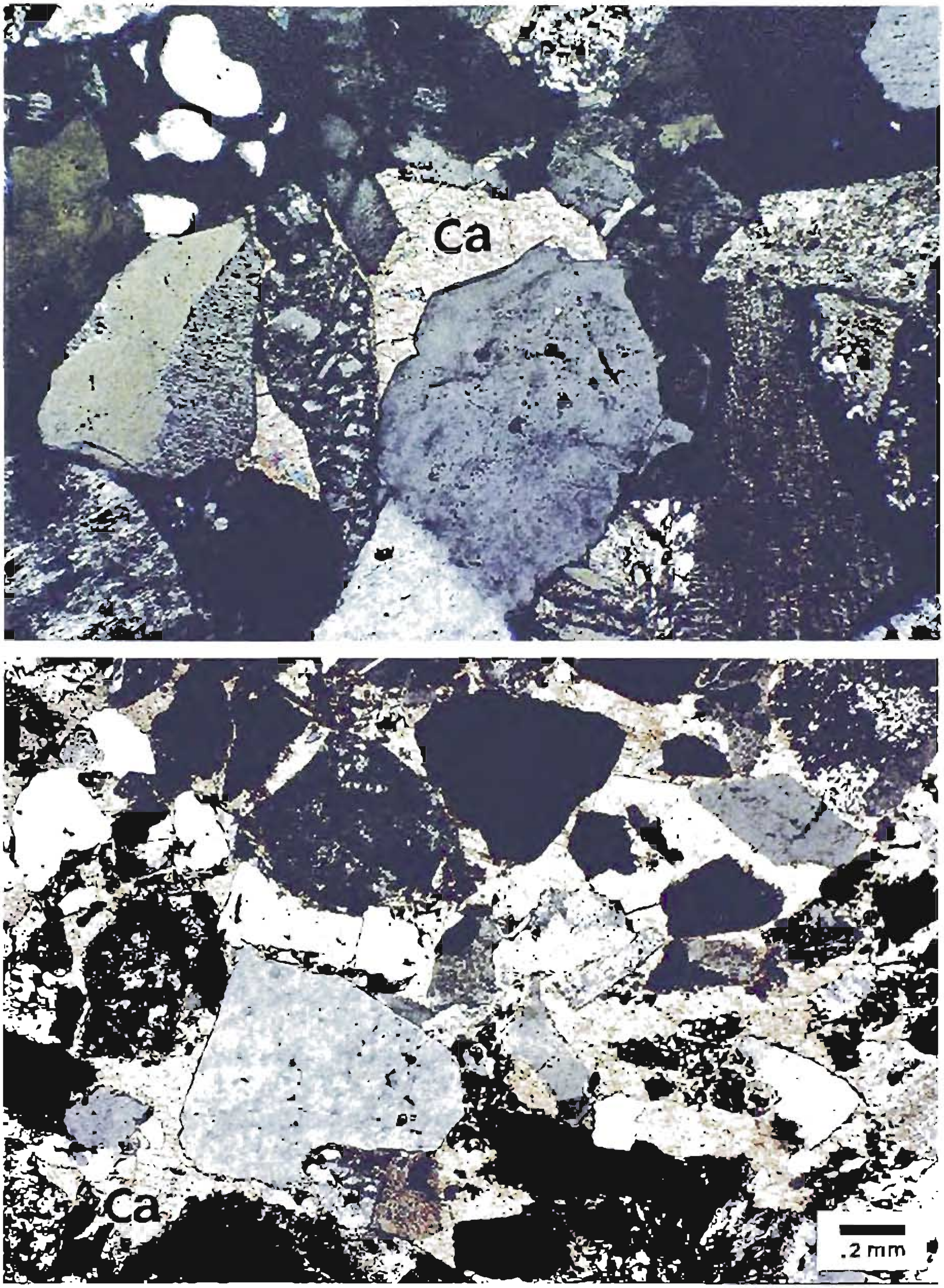


Figure 23. Top: Sparry calcite cement. Bottom: Calcite cement occluding intergranular porosity and partially replacing quartz and granitic framework grains. Exxon Felton No. 1-6. Depths 12,931 and 12,945 feet. 100X, XN

In some intervals of the Shell Whitledge core, early calcite cement accounts for up to 21% of the total. The calcite is typically a poikilotopic, pore-filling cement (Figure 24).

Authigenic Clays

Chlorite and kaolinite are the major authigenic clays (Figure 25). Chlorite is present as a late, void filling cement in minor amounts (less than 3%). Kaolinite is a late diagenetic mineral filling secondary pore spaces. It probably formed as replacement of feldspars. Kaolinite can account for up to 10% of the total in the more porous regions of the cores.

Porosity

In the marine facies, dissolution of fossil fragments and micrite generated enough calcite cement to effectively occlude porosity in all textures. Later carbonate cements generally occluded any remaining porosity. As a result, reservoir quality is typically poor in the marine-dominated intervals.

In nonmarine facies, these cementing episodes failed to occlude primary porosity. The remaining porosity served as a conduit that allowed corrosive fluids (organic acids) to circulate through the rock. These fluids dissolved granitic rock fragments and carbonate cements and generated a secondary porosity network.

Secondary porosity is the predominant porosity type observed in the normally pressured, non-marine intervals above the MCC. Porosity values range from zero in the matrix-dominated zones to a high of 34%. Enlarged intergranular and intragranular porosity are the two main forms of secondary porosity observed in both cores (Figure 26).

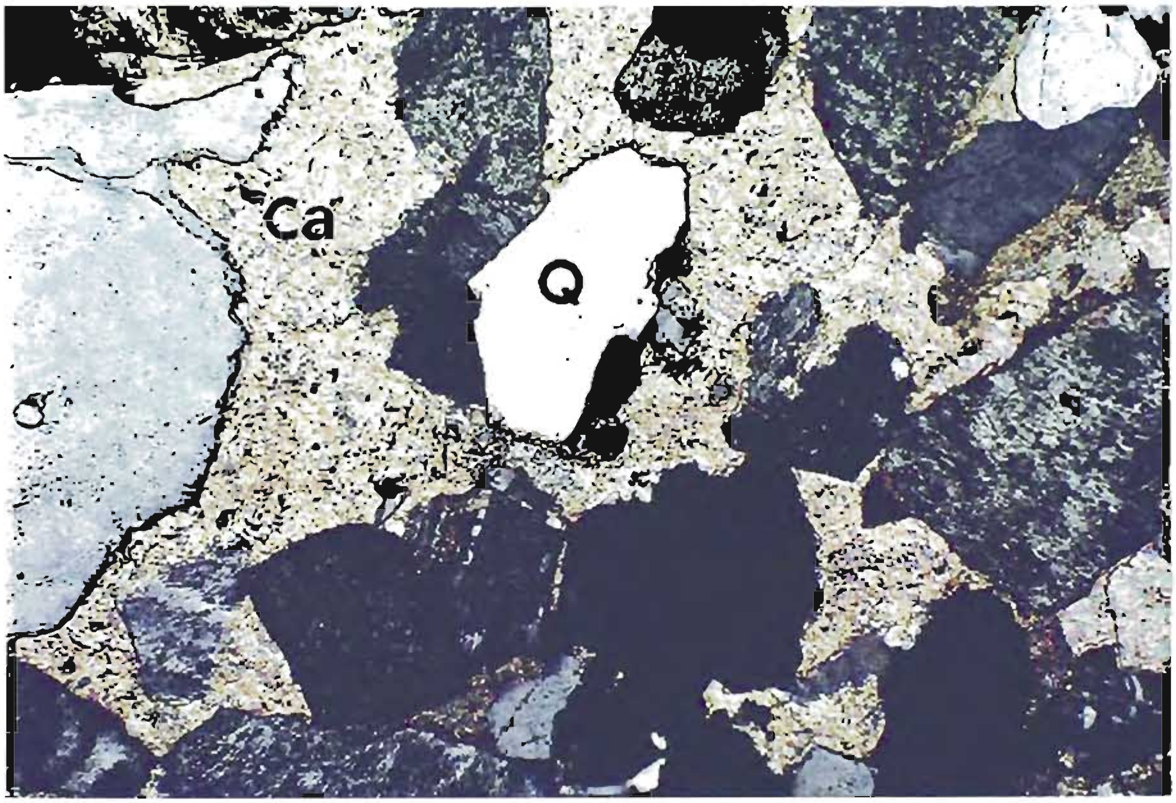


Figure 24. Poikilotopic calcite (Ca) cementing quartz (Q) and feldspar (F) grains. Shell Whitledge No. 1-8. Depth 8505 feet. XN, 100X.

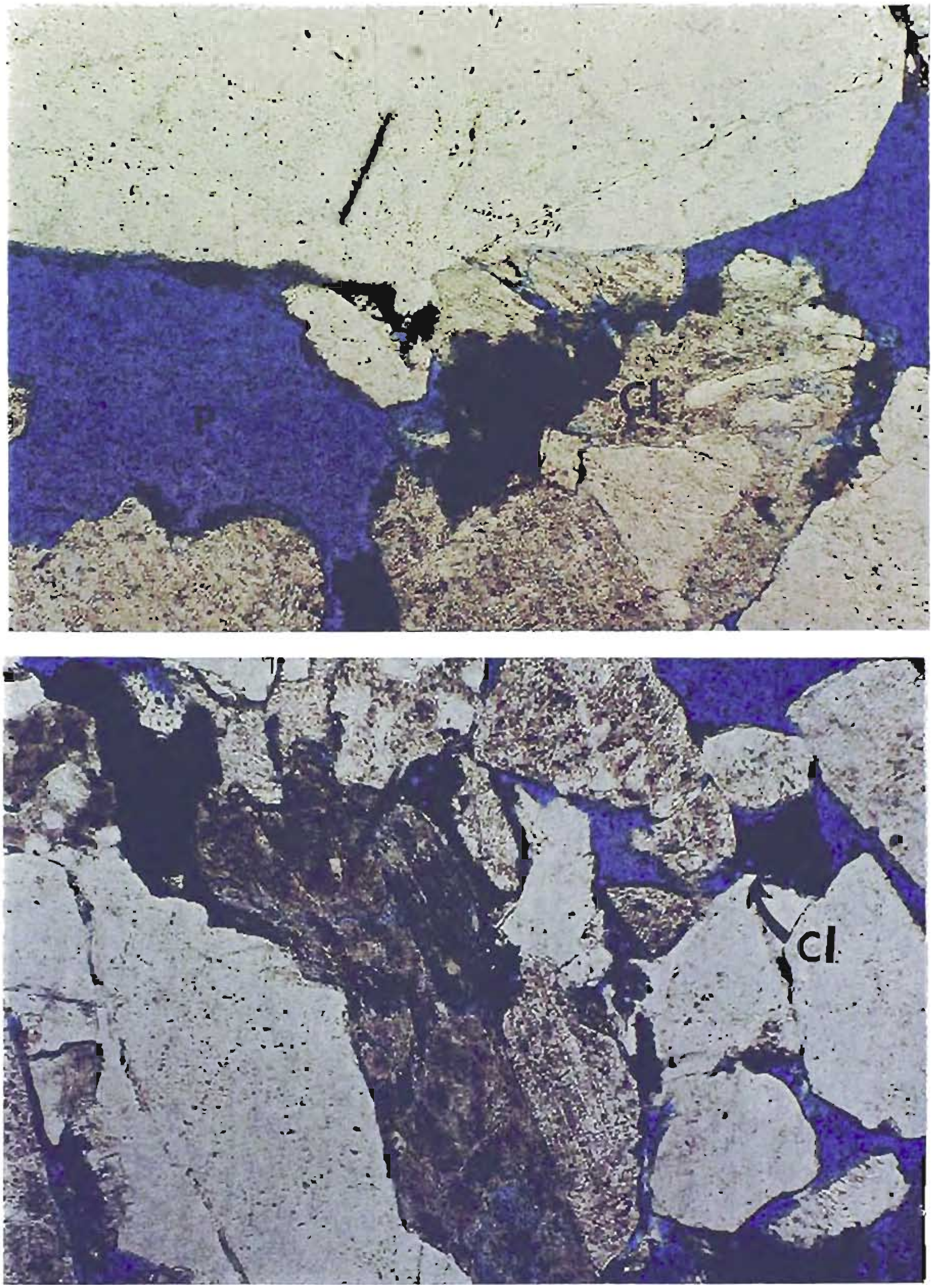


Figure 25 Authigenic clays (Cl) partially infilling porosity (P). Top: Shell Whitledge No. 1-8. Depth 8537 feet. PPL, 100X. Bottom: Exxon Felton No. 1-6 Depth 12,931 feet. PPL, 100X.

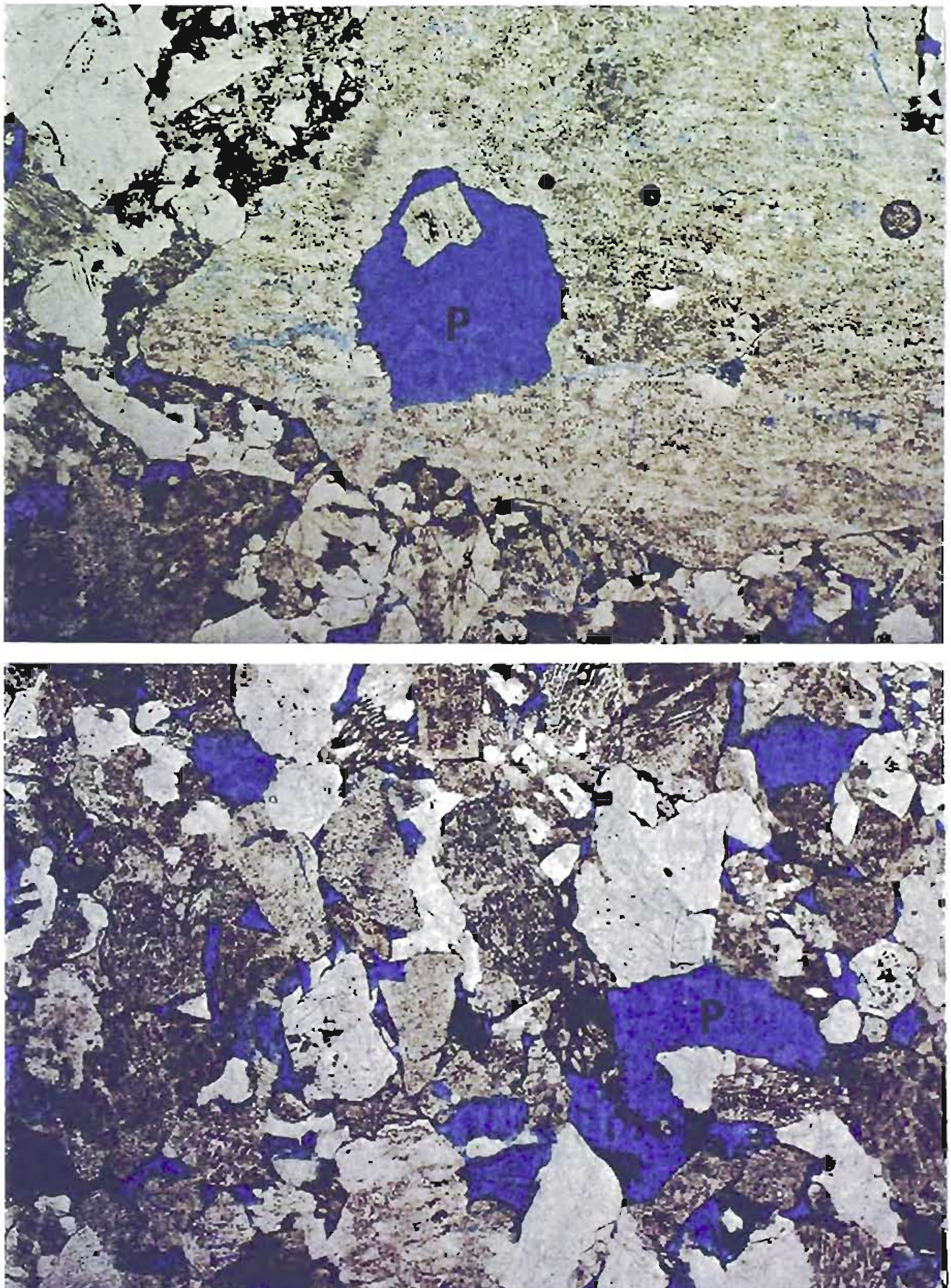


Figure 26. Top photo: Intragranular porosity (P). Shell Whitledge No. 1-8. Depth 8528 feet. PPL, 40X. Bottom photo: Intergranular porosity (P). Exxon Felton No. 1-6. Depth 12,931 feet. PPL, 40X.

Fault-Associated Reservoirs
Within the Overpressured Interval (MCC)

Overpressured strata in the vicinity of the Wichita frontal fault zone are highly indurated. This intense cementation is the direct result of diagenetic processes occurring between the overpressured rocks and a fault zone in hydraulic continuity with normally pressured strata. Cements tend to reflect framework grain mineralogy. Silica-rich rocks are silica cemented, while carbonate-rich rocks are primarily carbonate cemented.

Detrital Constituents

Quartz, feldspar, and granophyre, chert, and carbonate rock fragments are the most common detrital grains in the cores representing the overpressured domain. The quartz, feldspar, and granophyre rock fragments were derived from granitic rock fragments which form the core of the Wichita Mountains. The chert was derived from chert-rich Mississippian carbonates exposed on the Wichita Uplift.

The amount of detrital quartz grains ranges from trace amounts in some intervals of the GHK Kennemer and Hunt Bryant cores to more than 25% in the Gulf Community Paine core. Detrital quartz grains are abundant in the upper interval of the Hunt Bryant core (Figure 27). Both mono- and polycrystalline quartz were observed with a pronounced decrease in polycrystalline quartz with decreasing grain size.

Potassium feldspar (microcline and orthoclase), plagioclase, and microperthite are common in the granitic conglomerates and sandstones. The percentage of feldspar grains ranges from zero, in the chert conglomerate portion of the Hunt Bryant core and carbonate-dominated GHK Kennemer core, to 33% in the Gulf Community Paine.

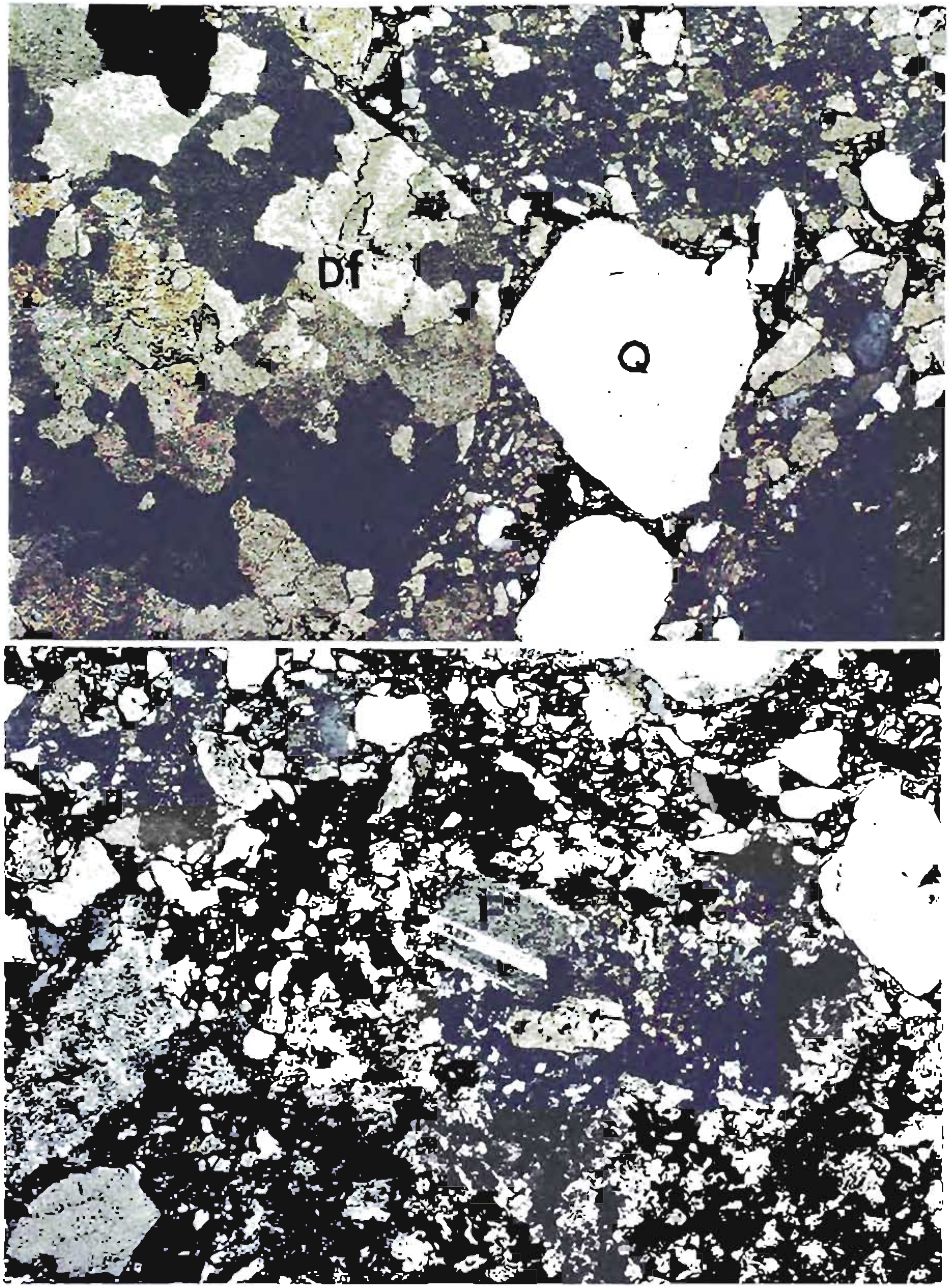


Figure 27. Top photo: Monocrystalline quartz (Q) and dolomite rock fragment (Df) in granitic conglomerate interval. Hunt Bryant No. 1-57. Depth 15,546 feet, XN, 40X. Bottom photo: Plagioclase feldspar (F). Gulf Community Paine No. 1. Depth 12, 342 feet. 40X, XN.

Plagioclase is the dominant feldspar form, and most grains exhibit some evidence of alteration and dissolution.

Granophyre rock fragments are found in the Gulf Community Paine core and the upper section of the Hunt Bryant core (Figure 28). Granophyre percentages range from zero in the lower chert conglomerate interval of the Hunt Bryant core and the carbonate pebble GHK Kennemer core to greater than 50%.

Chert is the most abundant detrital grain in the chert conglomerate. In the Hunt Bryant core, the amount of chert averages 67%. Several types of chert fragments were noted. Uniform, exceedingly fine grained microcrystalline quartz (Figure 29) was found throughout the Hunt Bryant core, while needle-like sponge spicule chert was observed in select zones (Figure 30).

Carbonate pebbles and oolites dominate the GHK Kennemer core (Figure 31). These carbonate clasts are typically well rounded and are often in contact with one another. Dolomite clasts are common in the GHK Kennemer core and upper interval of the Hunt Bryant core (Figures 27 and 32).

Detrital matrix is a significant component in some overpressured reservoir rocks. During periods of little/no tectonic activity, marine sedimentation resulted in the deposition of fine grained carbonate sediments. A calcarenite matrix is present in the GHK Kennemer core (Figure 32). A dark (clay) matrix comprises up to 40% of the mixed lithology Gulf Community Paine core (Figure 33).

<u>Diagenetic Imprints</u>

The cores within the overpressured domain exhibit numerous compaction

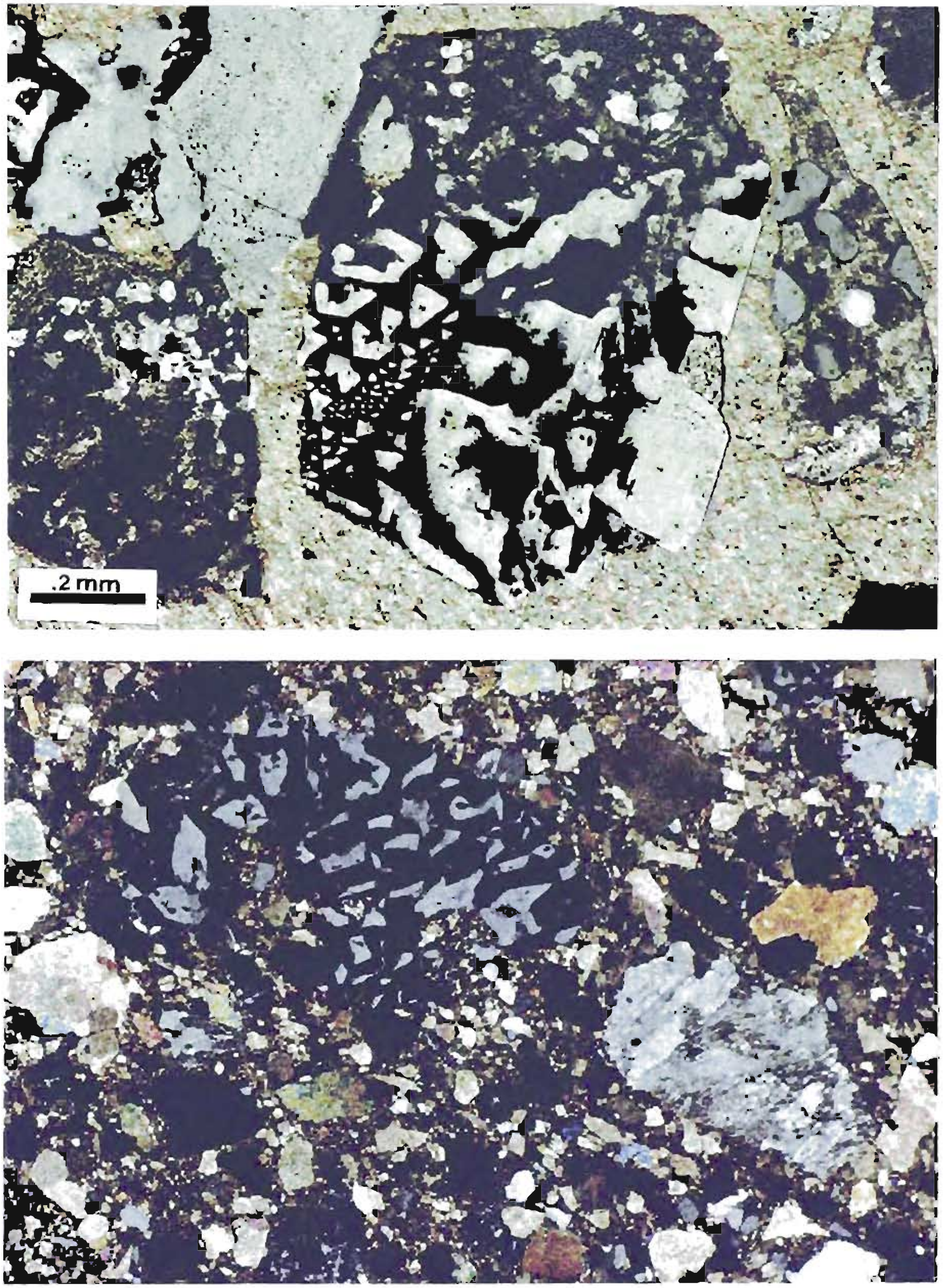


Figure 28. Plutonic rock fragments (granophyre) in mixed lithology washes. Top photo: Gulf Community Paine No. 1. Depth 12,368 feet. 40X, XN. Bottom photo: Hunt Bryant No. 1-57. Depth 15,546 feet. 20X, XN.

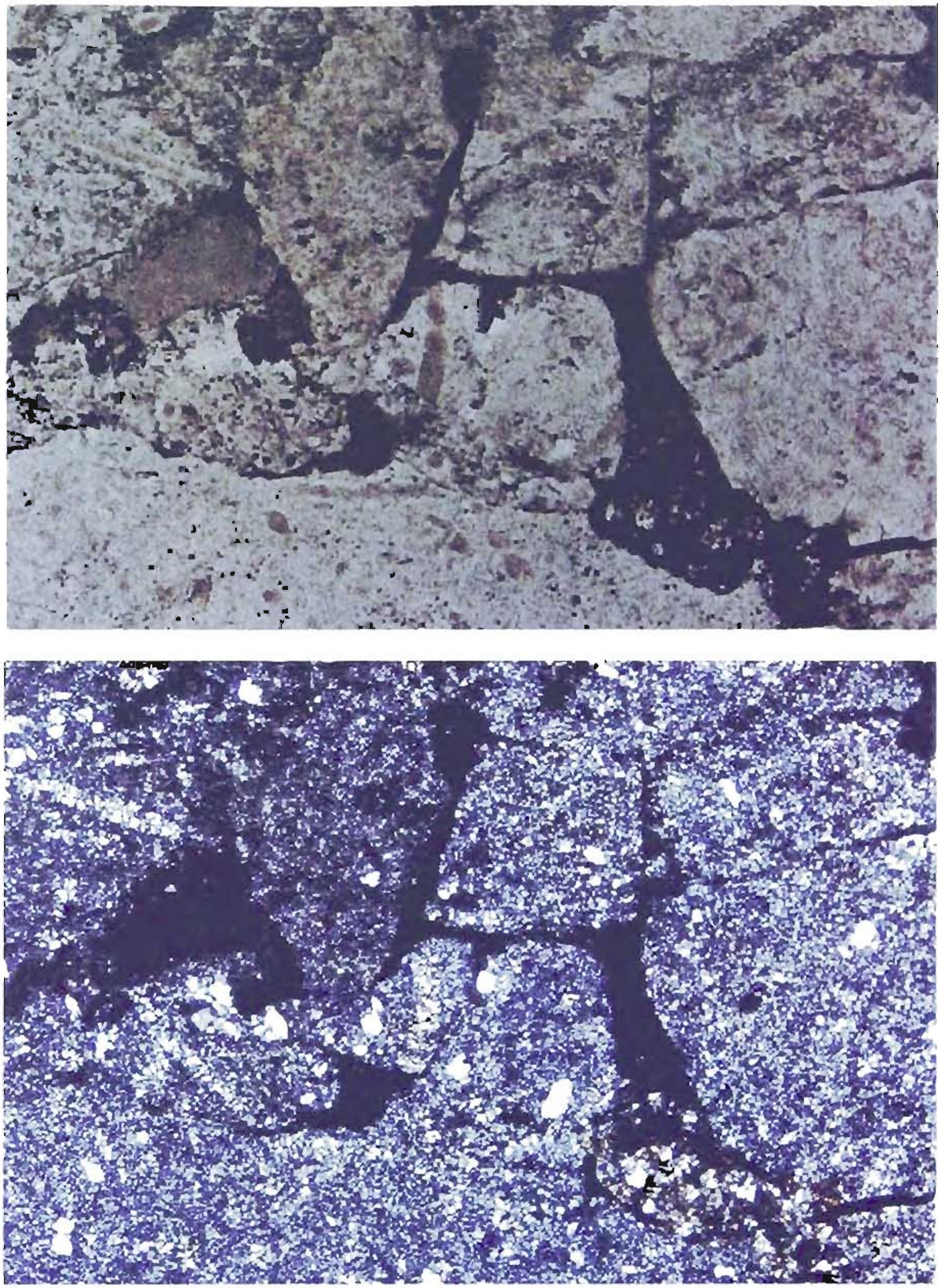


Figure 29. Uniform, exceedingly fine grained microcrystalline detrital quartz (chert). Hunt Bryant No. 1-57. Depth 17, 992 feet. 40X. Top photograph in PPL, bottom photomicrograph in XN.

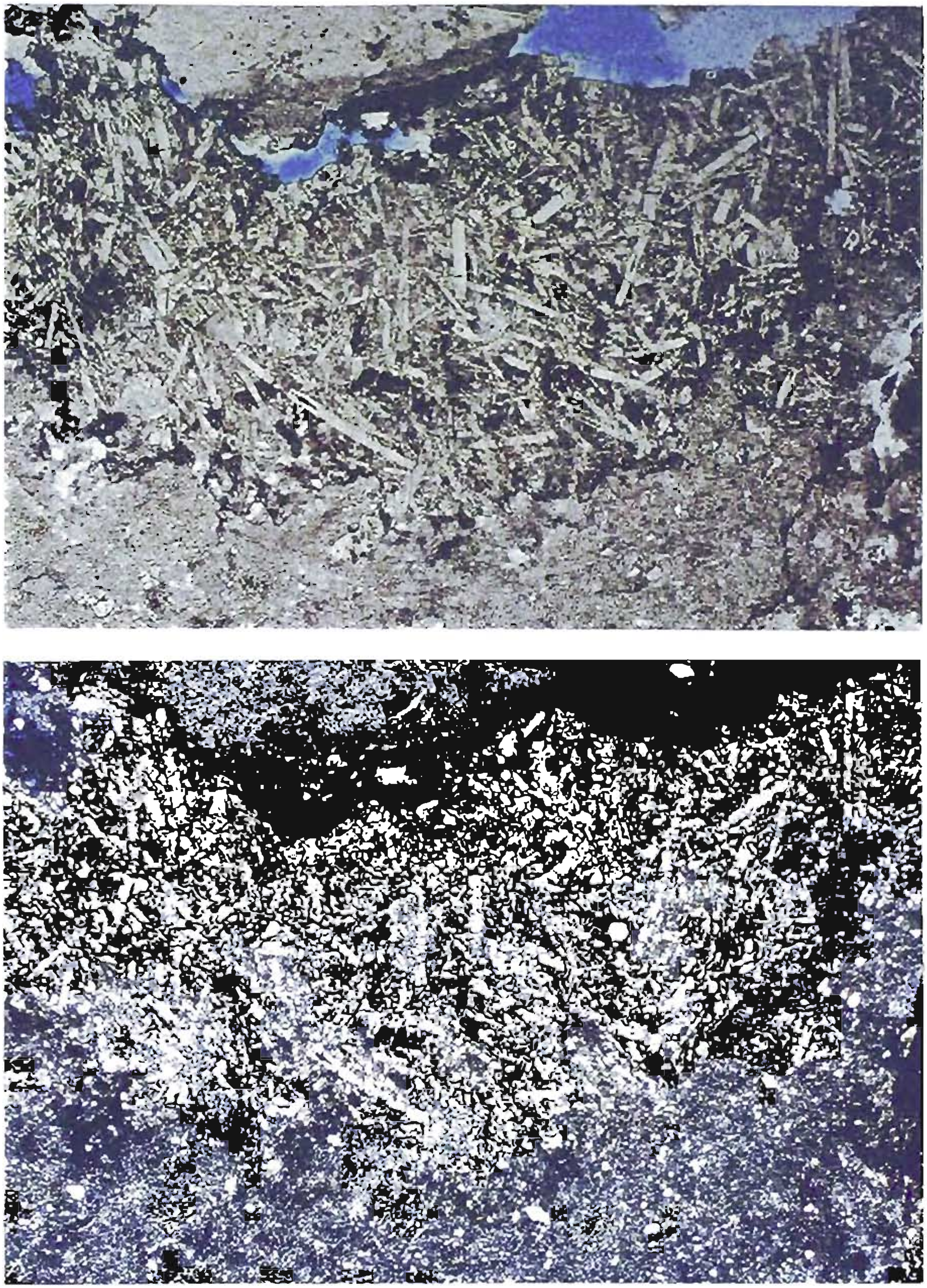


Figure 30. Needle-like sponge spicule chert. Hunt Bryant No. 1-57. Depth: 17,989 feet. Top photograph in PPL, bottom photomicrograph in XN. 40X.

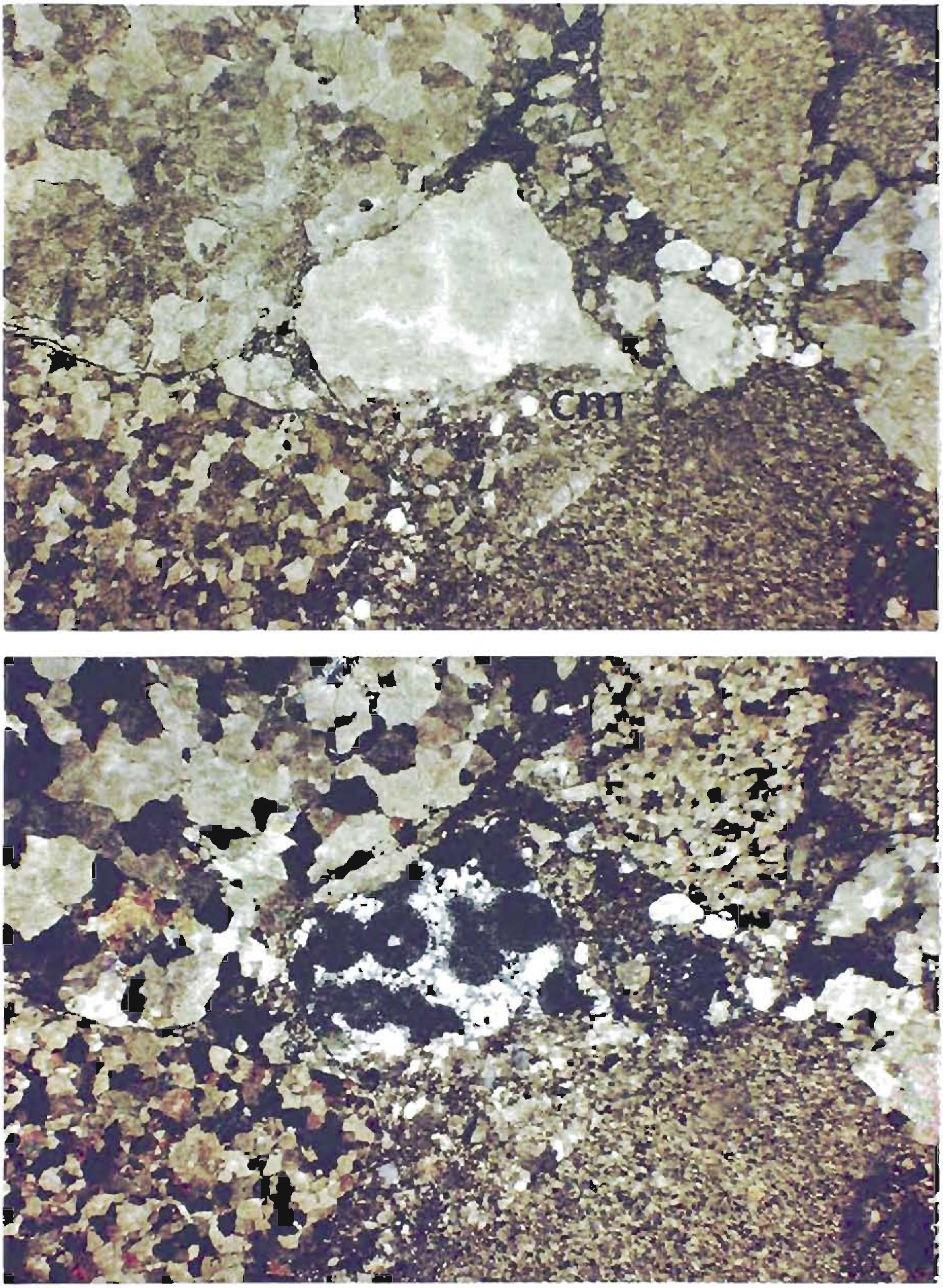


Figure 31. Carbonate pebbles and oolites in a calcarenite matrix (Cm). GHK Kennemer 1-22. Depth 13,815 feet. Top photomicrograph in PPL, bottom photomicrograph in XN.

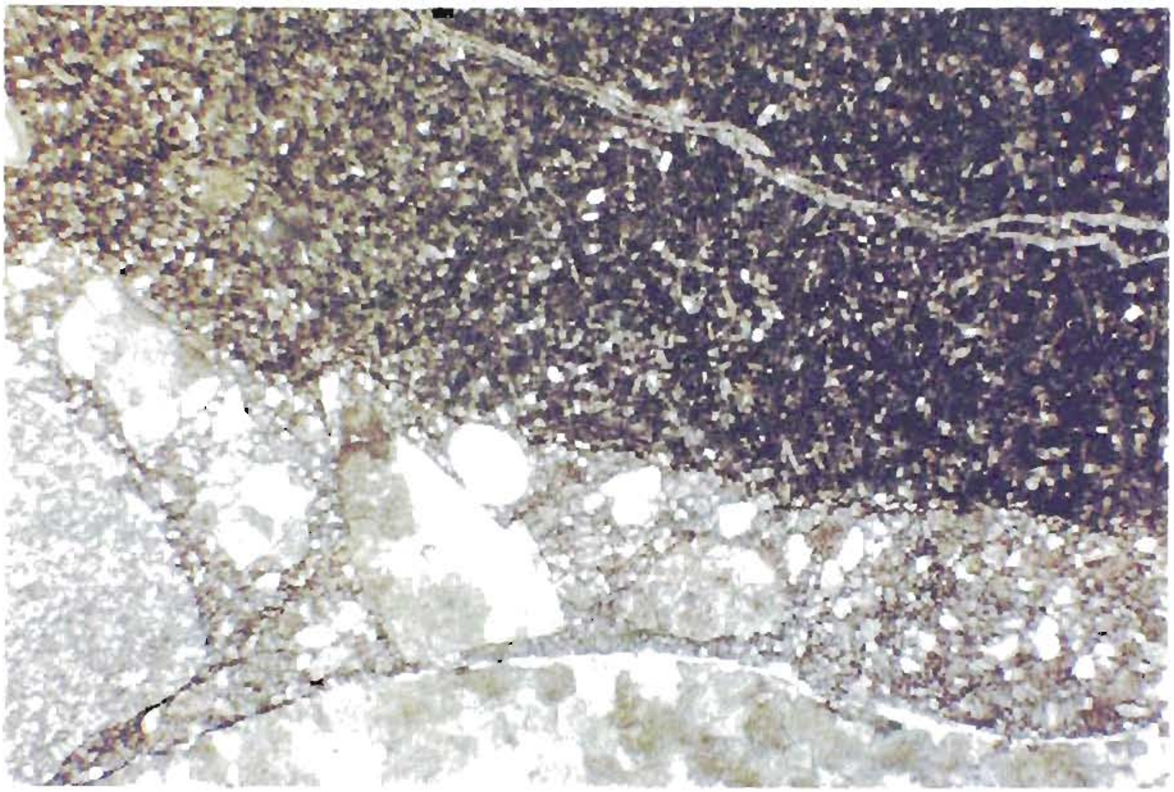


Figure 32. Dolomite pebbles in a dolomite and sand matrix. Extensive dissolution front occurs at pebble boundaries. GHK Kennemer No. 1-22. Depth 15,031 feet. XN, 100X (photo by J. Puckette).

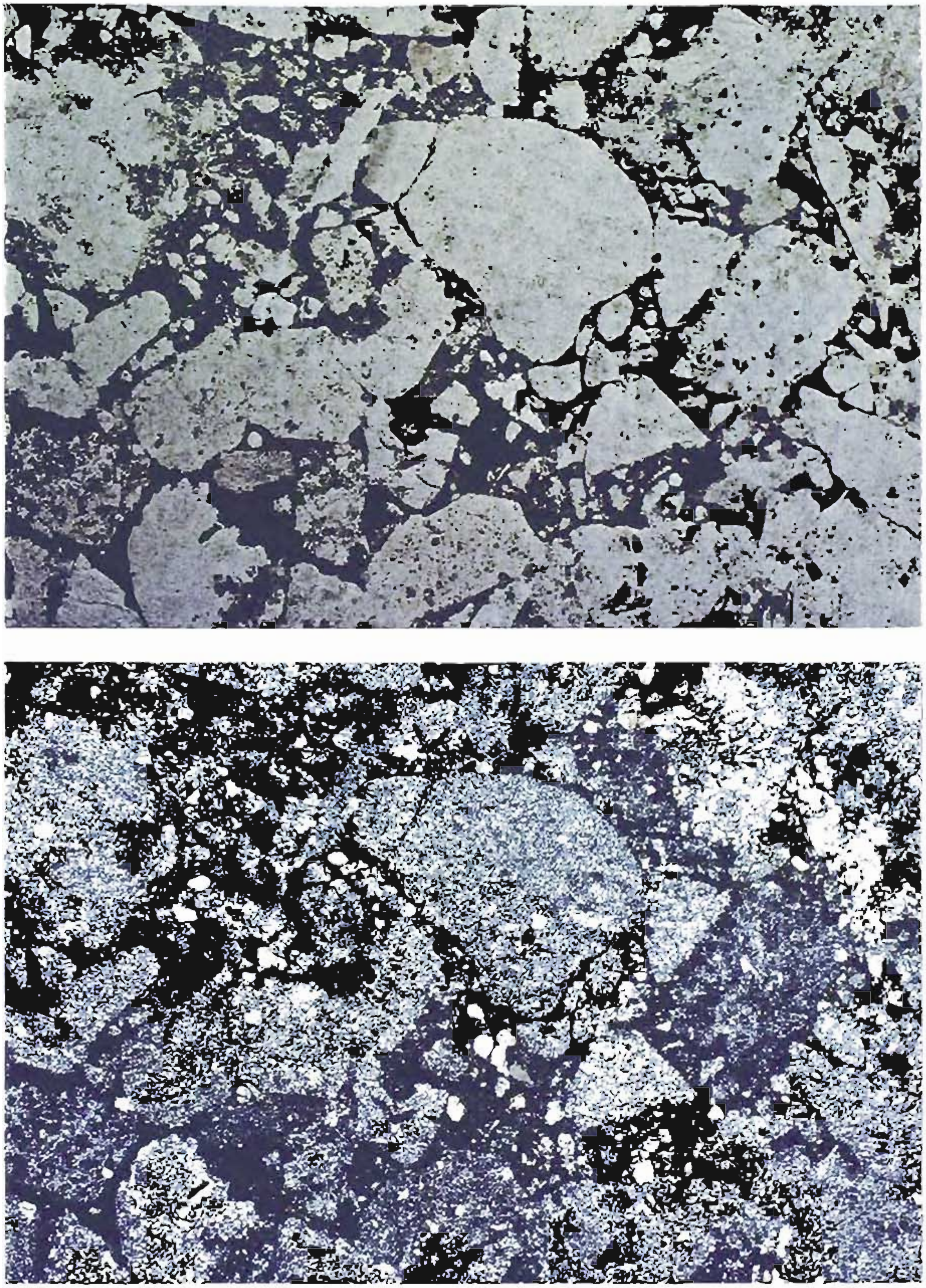


Figure 33. Dark black, detrital clay matrix Gulf Community Paine No. 1. Depth 12, 359 feet. 40X. Top photomicrograph in PPL, bottom photomicrograph in XN.

features. Sutured and penetrating grain contacts are common (Figure 34). Stylolites, with their fine saw-tooth appearance, are another indication of chemical compaction (Figure 35).

Silica

Dissolution-derived silica was precipitated as syntaxial quartz overgrowths, coarse equant quartz (macroquartz), chert (microquartz), and chalcedony (radial-fibrous quartz).

Syntaxial quartz overgrowths were observed in the Gulf Community Paine and Hunt Bryant cores (Figure 36). The overgrowths are often separated from detrital grains by a dust rim. Overgrowth percentages are relatively low (less than 2%).

Pore-filling coarse equant quartz cement is observed in the Hunt Bryant and Gulf Community Paine cores (Figures 37 and 38). Macroquartz occurs as grain-surrounding rims and alone. The percentage ranges from a trace to roughly 5% of the total rock.

Chert/microquartz cements larger (detrital) chert grains in the chert conglomerate interval of the Hunt Bryant core (Figure 39). In this particular core, the amount of chert cement is highly variable, ranging from less than 1% to 30%. Chert typically occurs as a pore-filling cement.

Radial fibrous, void-filling chalcedony is a relatively minor component of the Hunt Bryant core (Figure 40).

Carbonate

Carbonate cements include calcite and dolomite. Calcite cement is found in the

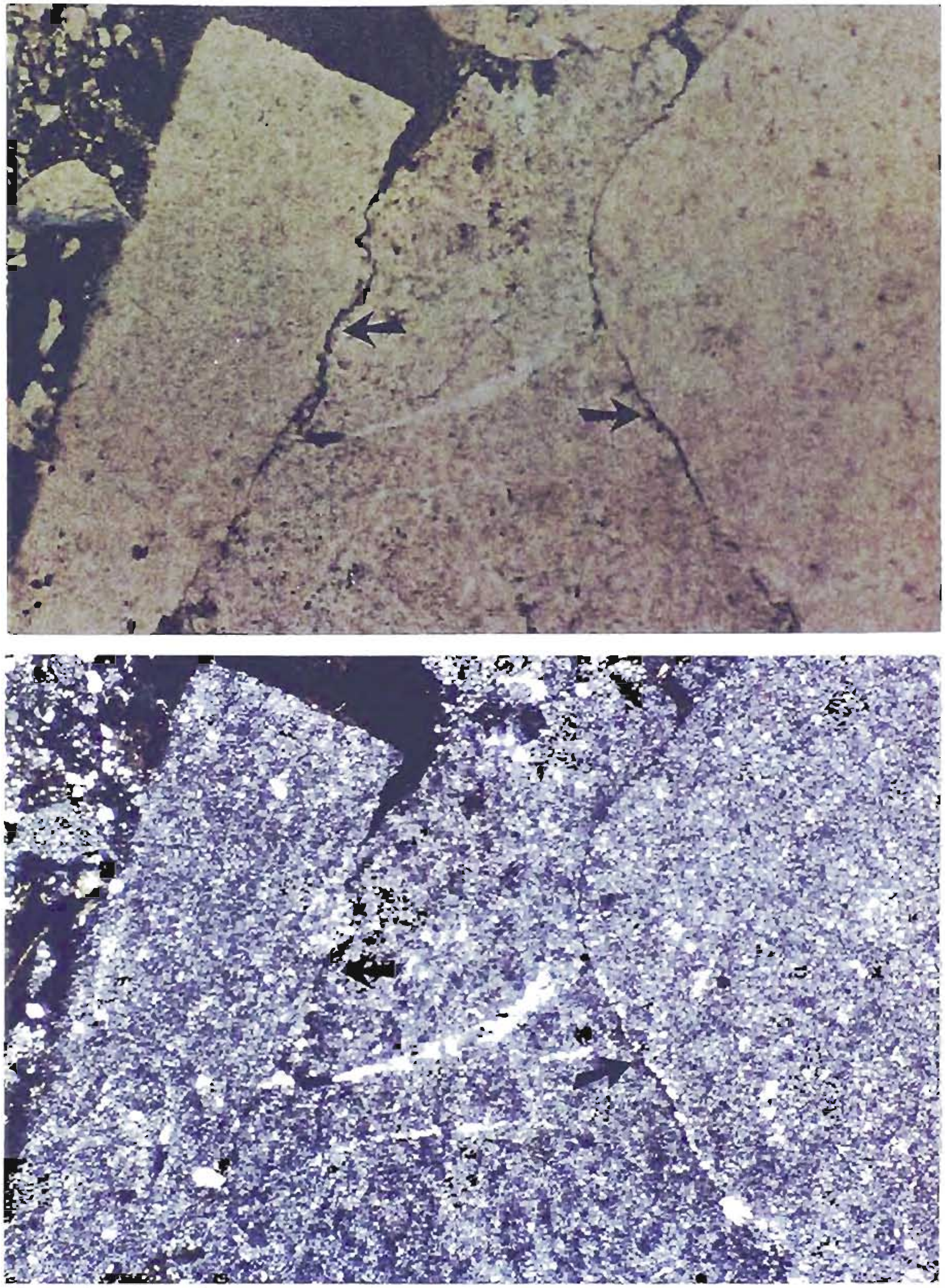


Figure 34. Sutured-seam contacts (arrows) between grains in chert pebble conglomerate indicating stress-induced dissolution. Hunt Bryant No. 1-57, Wheeler County, Texas. Depth 18,007 feet. Top photo in PPL, bottom photo in XN, 100X (photo by J. Puckette).

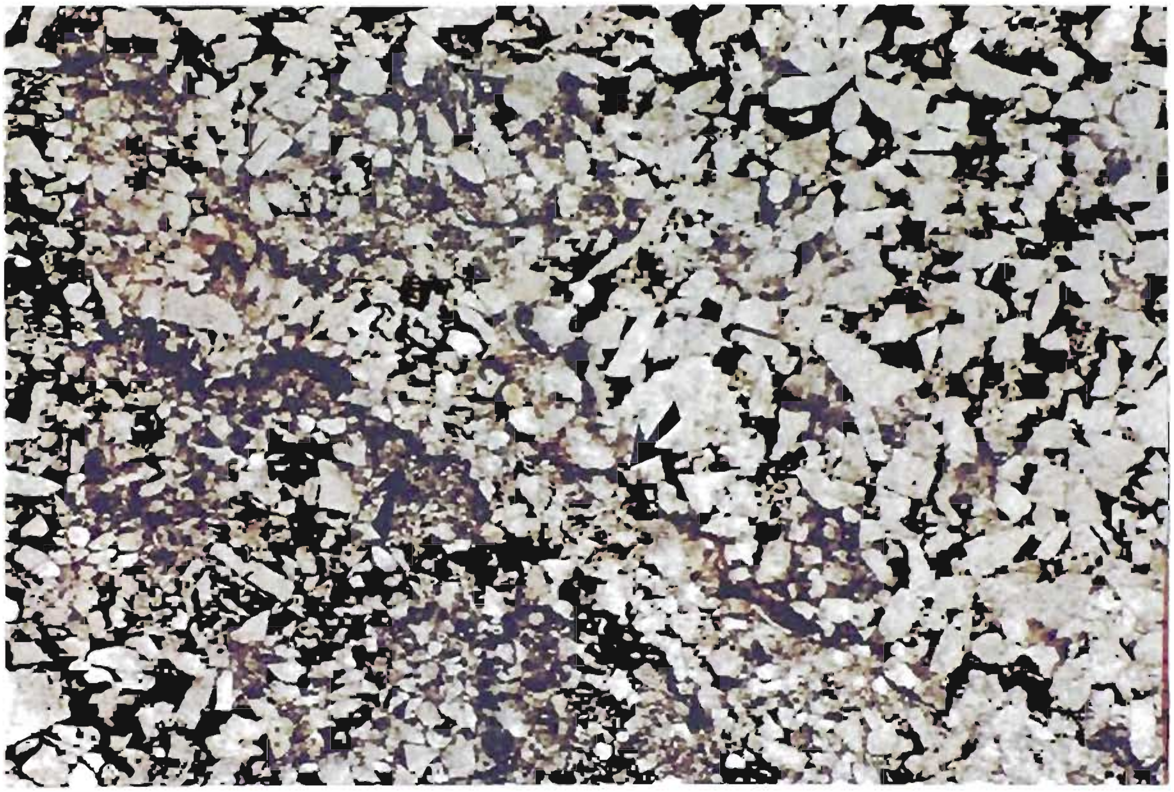


Figure 35. Stylolites (arrows) with fine saw-tooth appearance. Hunt Bryant No. 1-57. Depth 18,000 feet, PPL, 40X (photo by J. Puckette).

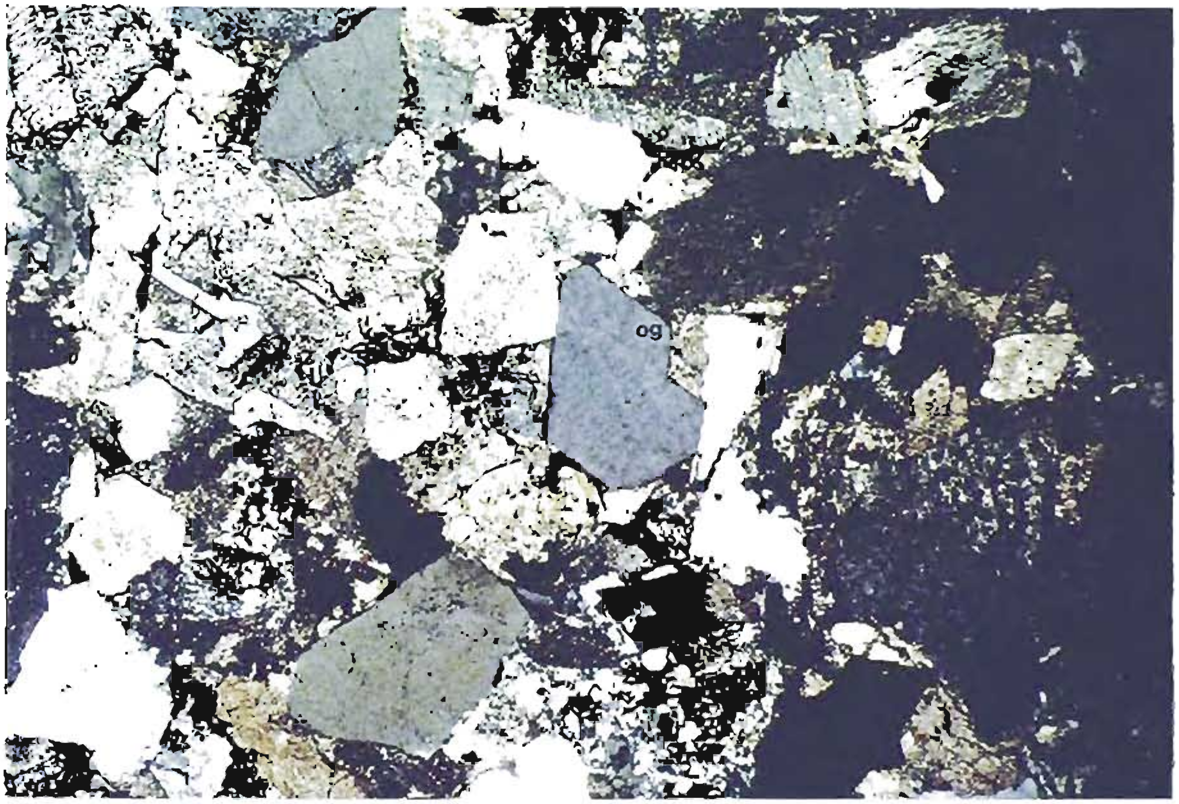


Figure 36. Syntaxial quartz overgrowth (OG). Note that the dust rim separating the overgrowth from the grain is absent. Gulf Community Paine No. 1. Depth 12,382 feet. 40X, XN.

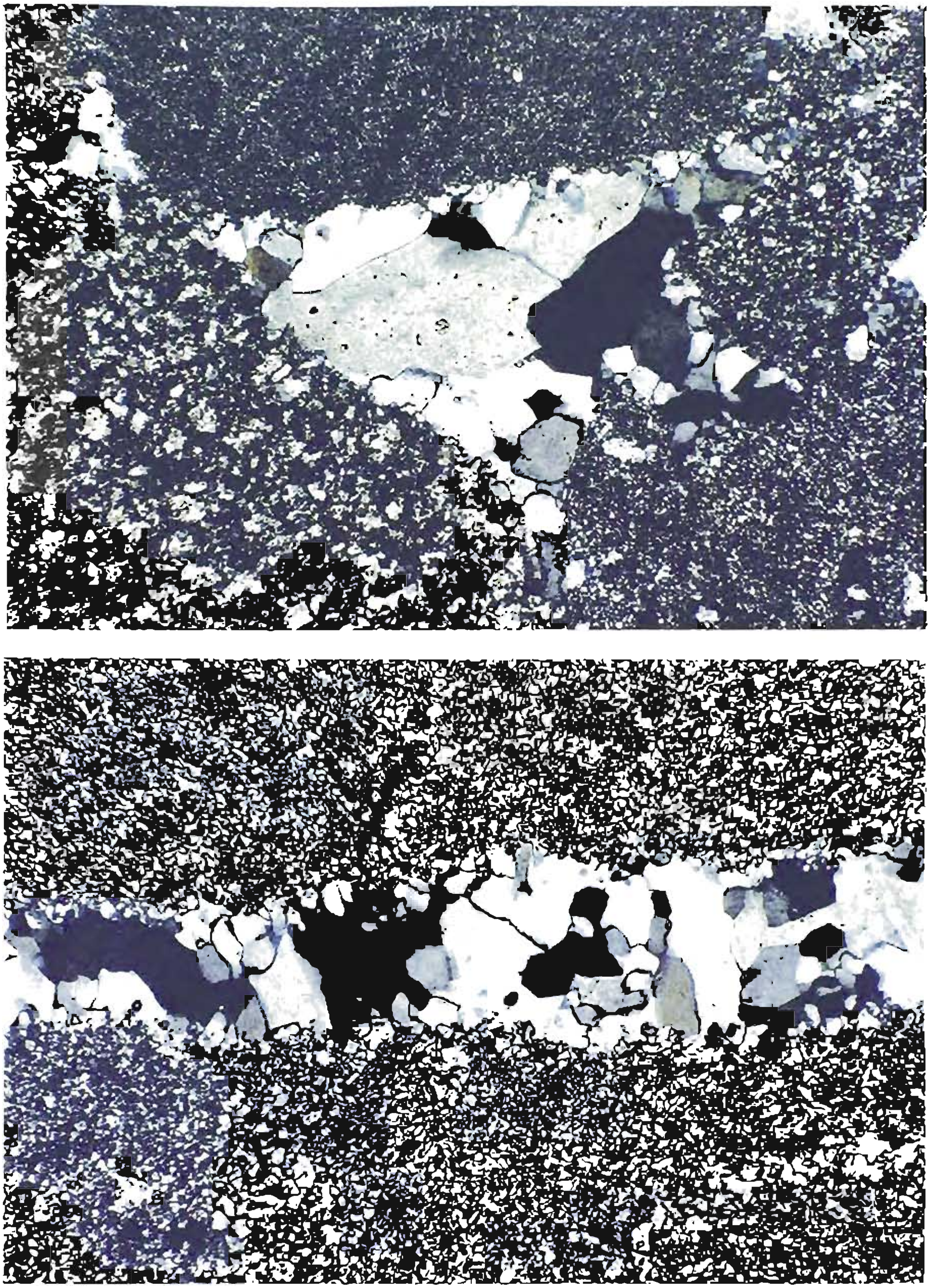


Figure 37. Coarse, equant quartz cement occluding intergranular porosity. Hunt, Bryant No. 1-57. Depths 17,973 feet (top) and 17,988 feet (bottom) XN, 100X.

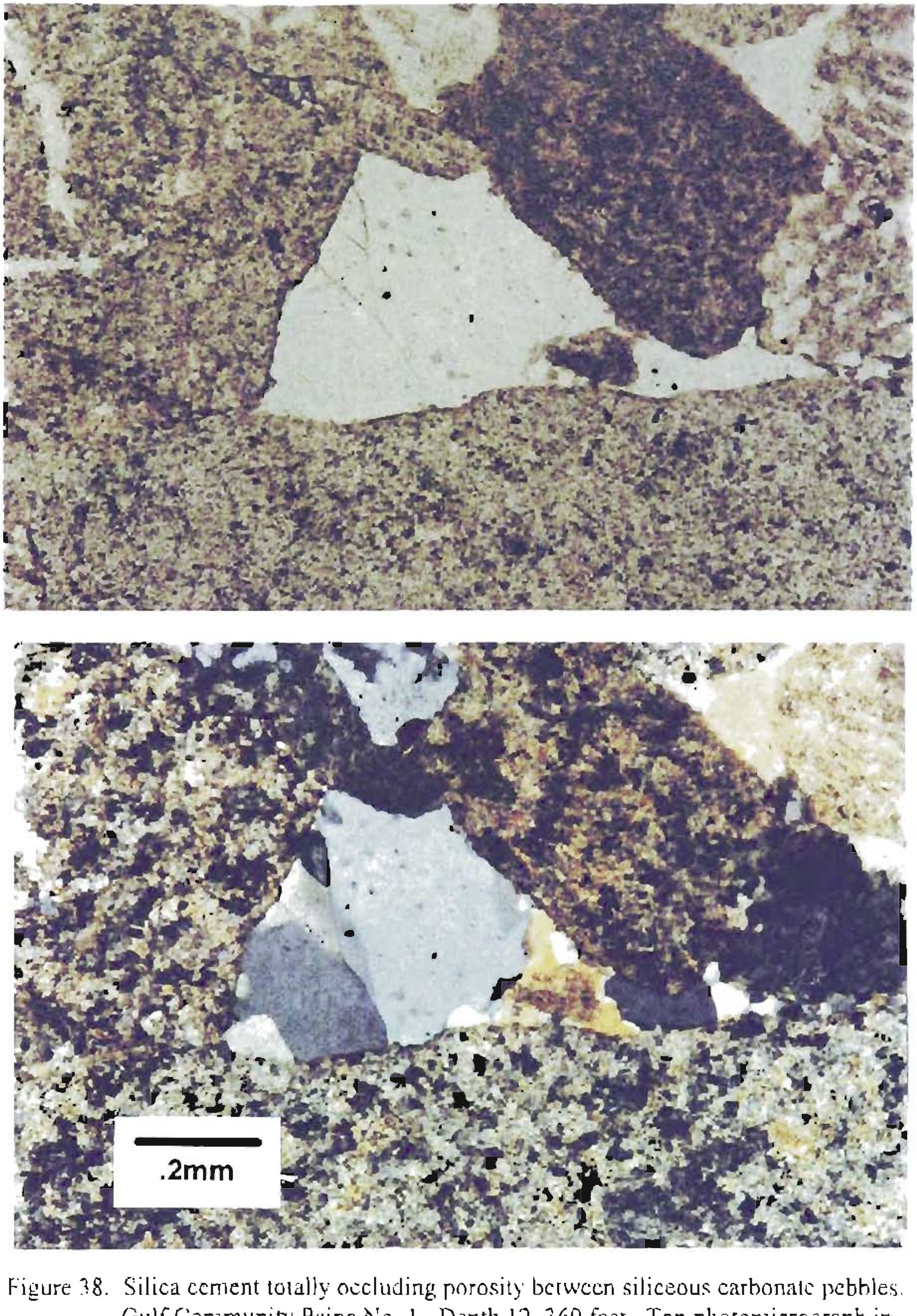


Figure 38. Silica cement totally occluding porosity between siliceous carbonate pebbles. Gulf Community Paine No. 1. Depth 12, 369 feet. Top photomicrograph in PPL, bottom photomicrograph in XN (photo by J. Puckette) 200X.

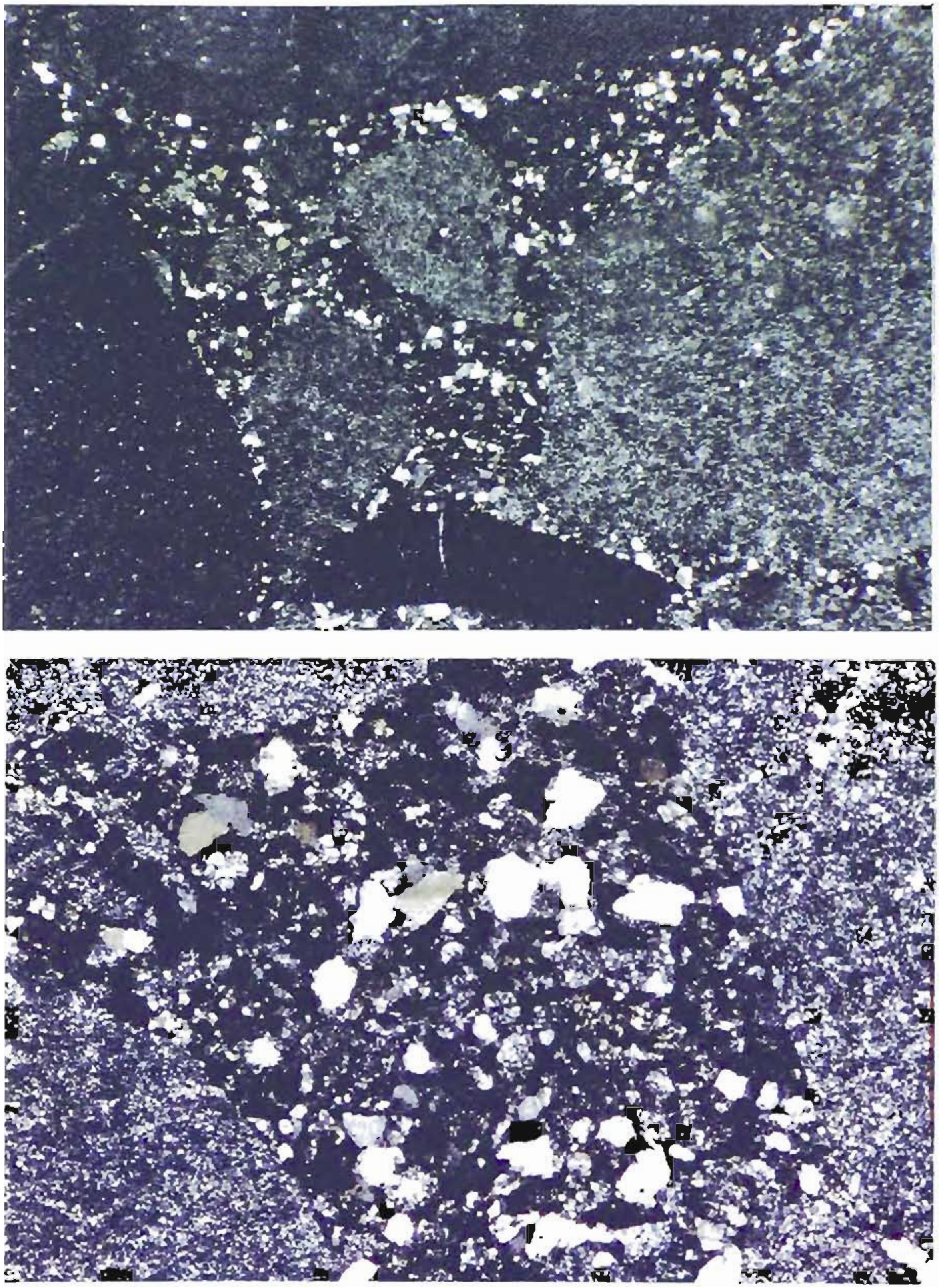


Figure 39. Chert/microquartz cementing larger chert grains. Hunt Bryant No. 1-57. Depth 17,973 feet. Top photo 40X, bottom photo 40X (photo by J. Puckette).

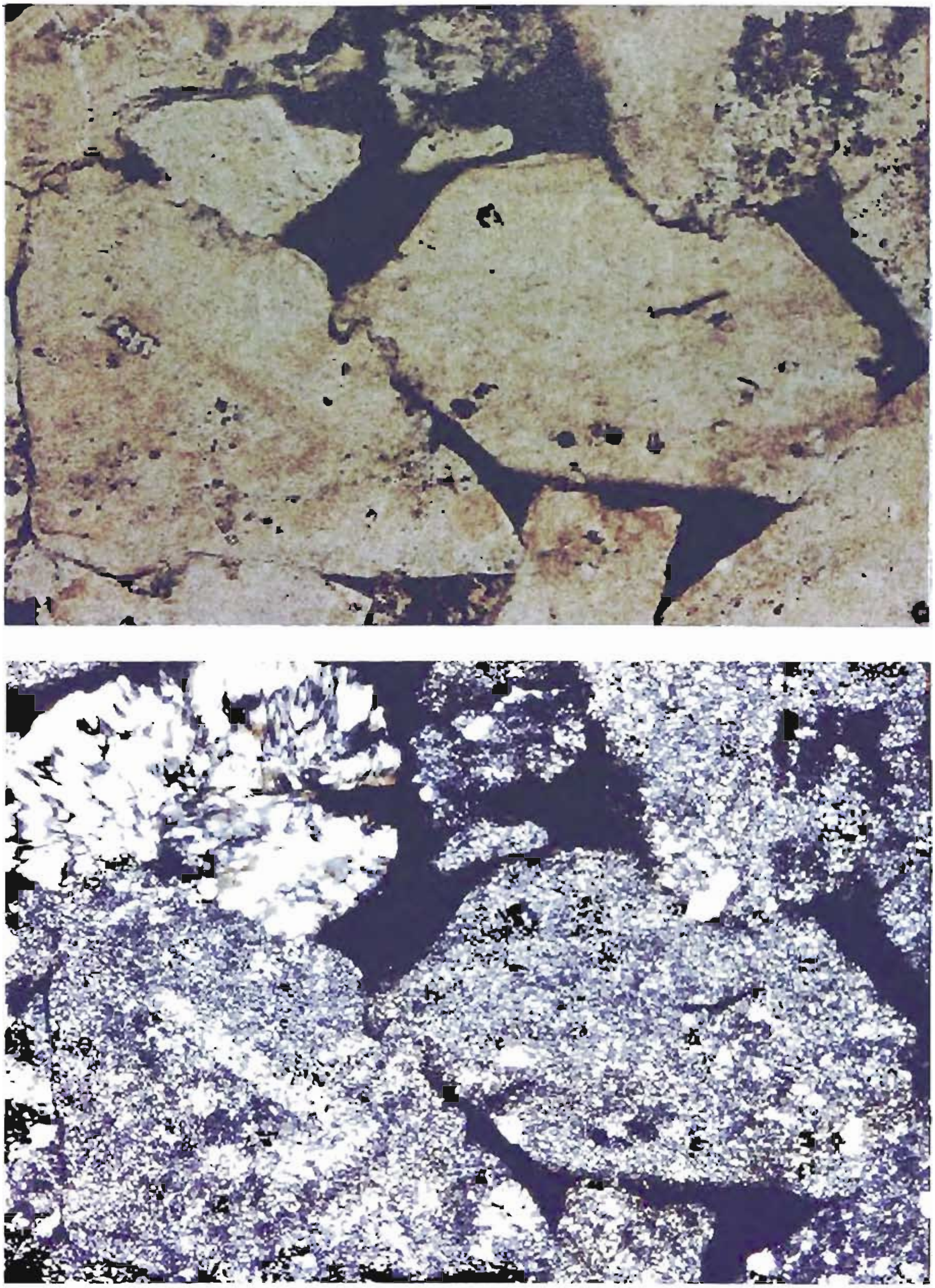


Figure 40. Radial-fibrous chalcedonic quartz cement and sutured-seam grain contacts. Hunt, Bryant No 1-57. Depth 18,004 feet. Top photo in PPL, bottom photo in XN, 100X (photo by J. Puckette).

Gulf Community Paine core, the GHK Kennemer core, and the upper conglomeratic interval of the Hunt Bryant core. Calcite is thought to be the product of early diagenesis. It varies from patchy to completely pore-filling (poikilotopic) cement (Figure 41). Calcite is also found, replacing detrital grains such as chert, feldspar, and detrital matrix.

An earlier investigation, by Al-Shaieb and others (1993c), examined the origin of calcite in the Gulf Community Paine core. They found that the calcite cement was imported from an outside source. In this core, C^{13} and O^{18} values (-8.1 and -15.1, respectively) for the calcite indicate that the carbon was partially derived from an organic source, while the oxygen isotope ratios indicate higher temperature fluids. Since the pebble conglomerate contains few stress-induced features, the calcite may have precipitated relatively early from heated fluids that migrated from the deeper regions of the basin. Homogenization temperatures (T_h) around 138°C for fluid inclusions in the calcite support this interpretation. Calcite and silica cements effectively isolated grains from corrosive pore fluids that dissolved rock constituents in the shallower core.

Xenotopic dolomite is a major cement in the upper granitic conglomeratic interval of the Hunt Bryant core. This type of dolomite is a relatively deep-burial, late-stage diagenetic mineral.

Authigenic Clays

Chlorite is the main authigenic clay mineral (Figure 42). It is typically found infilling pores and exhibits various degrees of silicification (chert replacement). Kaolinite and illite are locally significant.

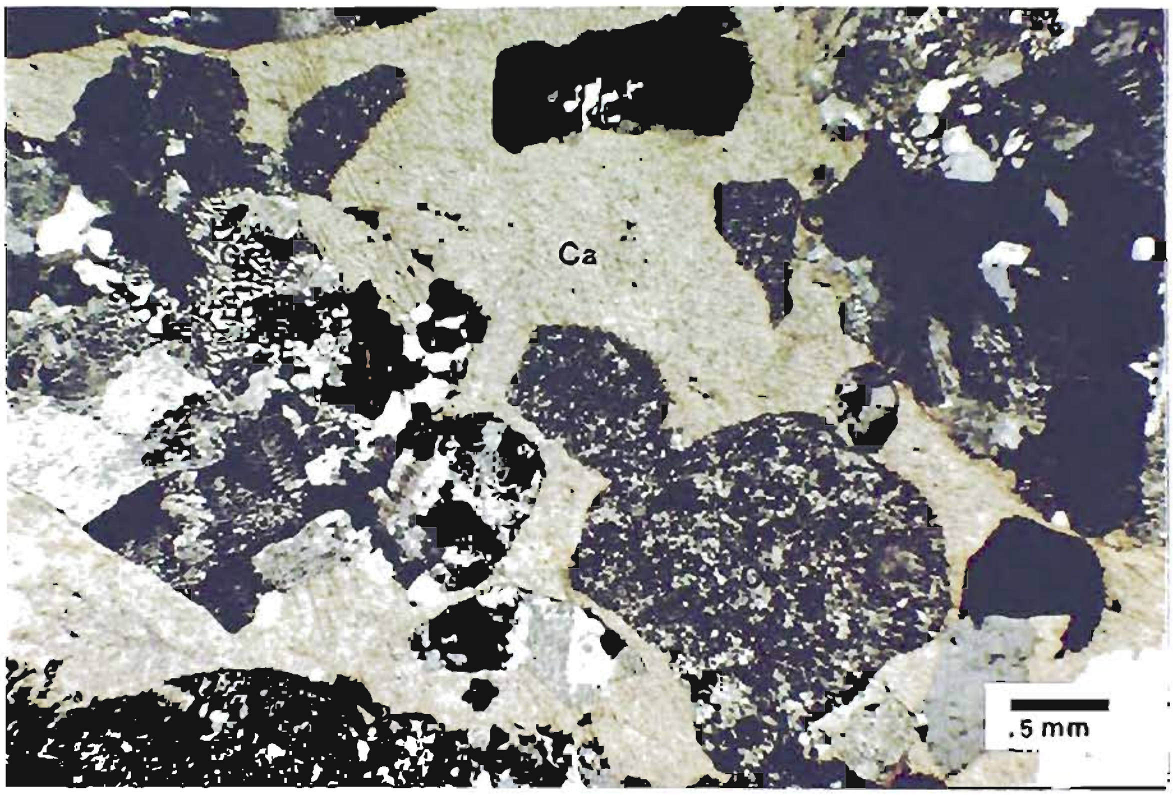


Figure 41. Calcite cement (Ca) in mixed-lithology pebble conglomerate. Granophyre (Gr) and silicified carbonate pebbles (Cb) are common. Gulf Community Paine No. 1. Depth 12, 369 feet, XN, 100X (photo by J. Puckette).

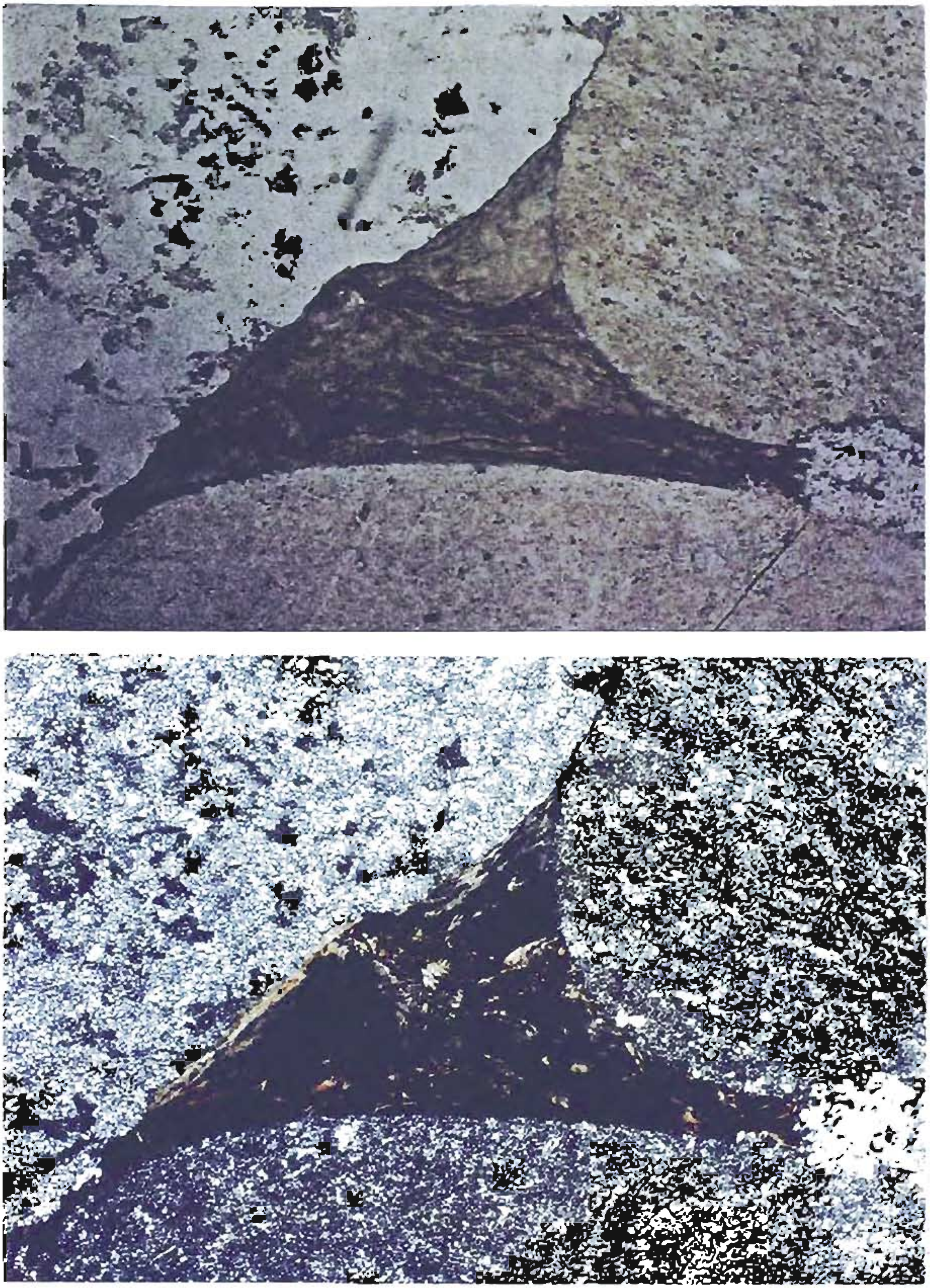


Figure 42. Pore-filling diagenetic chlorite. Hunt Bryant No. 1-57. Depth 17,991 feet. Top photo in PPL, bottom photo in XN. 40X.

Porosity

Silica liberated from compaction-induced pressure solution has essentially occluded all primary porosity in the chert conglomerate intervals. Secondary porosity formed by the dissolution of matrix and detrital grains was subsequently occluded by authigenic clays (chlorite) and carbonate cements.

Several coarse-grained, feldspar-rich intervals of the mixed lithology Gulf Community Paine core have escaped the intense fault-associated cementation (Figure 43). Secondary porosity is the major porosity type. This porosity is the result of the partial and/or complete dissolution of grains (especially feldspar and granophyre). Primary porosity is rare, but some primary porosity must have been preserved to provide conduits for migration of fluids through the rock.

Fault-Associated Reservoirs Below the Overpressured Interval (MCC)

Normally pressured rocks below the MCC are represented by the Henryhouse Formation and Chimneyhill Subgroup of the Hunton Group. Thin section examination revealed extensive diagenetic modifications which have significantly altered the original fabric. Silica and carbonate cements are present, but they do not completely occlude porosity. Like the normally pressured rocks above the MCC, these rocks were not affected by fault-associated cementation processes. As a result, porosity is observed below 20,000 feet.

Lime/dolomudstone and, to a lesser degree, wackestone are the main lithologies observed. It should be noted that the thin section examination included additional

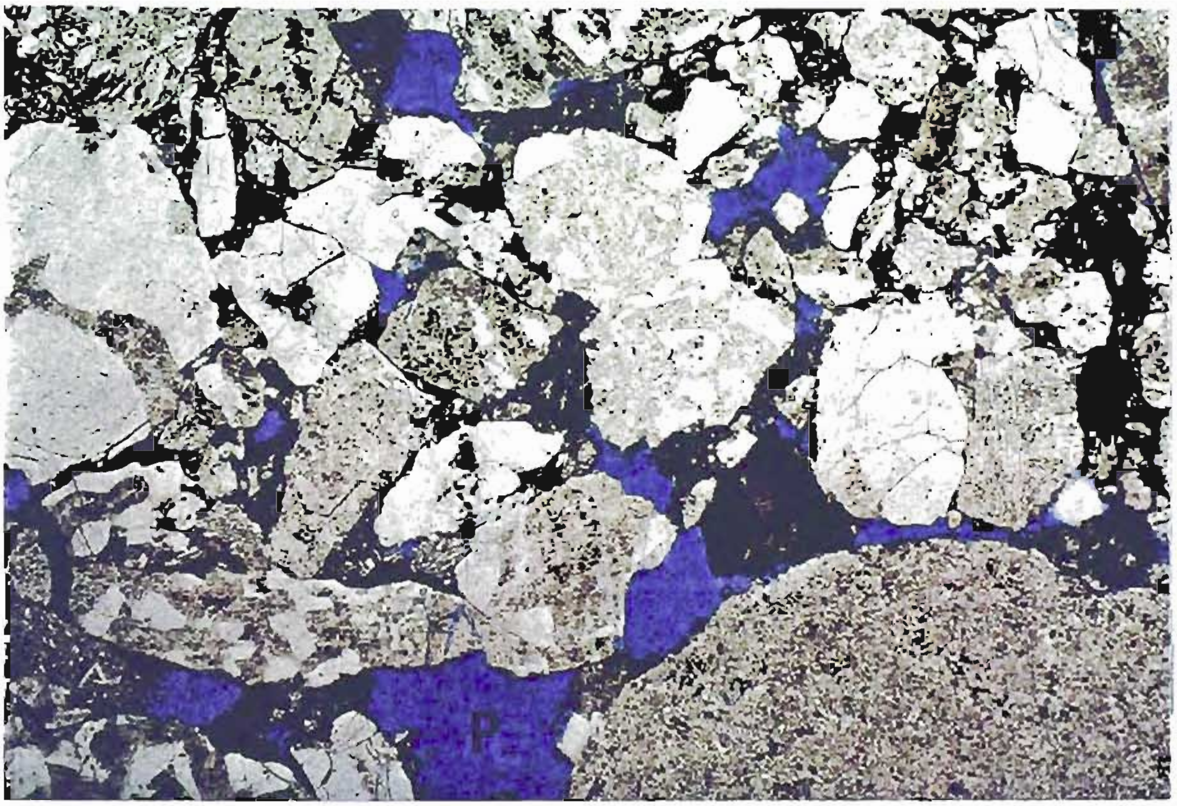


Figure 43. Secondary, intergranular porosity preserved in the overpressured interval. Gulf Community Paine No. 1. Depth 12,342 feet. 40X, PPL.

intervals not covered in the core description/interpretation portion of the study.

Detrital Constituents

Algae is the most abundant allochemical constituent. Algal laminations have been preserved in the upper (supratidal) cored interval and are evident in thin-section (Figure 44, top). Fossils are rare, but brachiopods, trilobites, crinoids, and mollusks were observed (Figures 44, bottom). Peloids, most probably of fecal origin, are common in the intertidal zones (Figure 45, top).

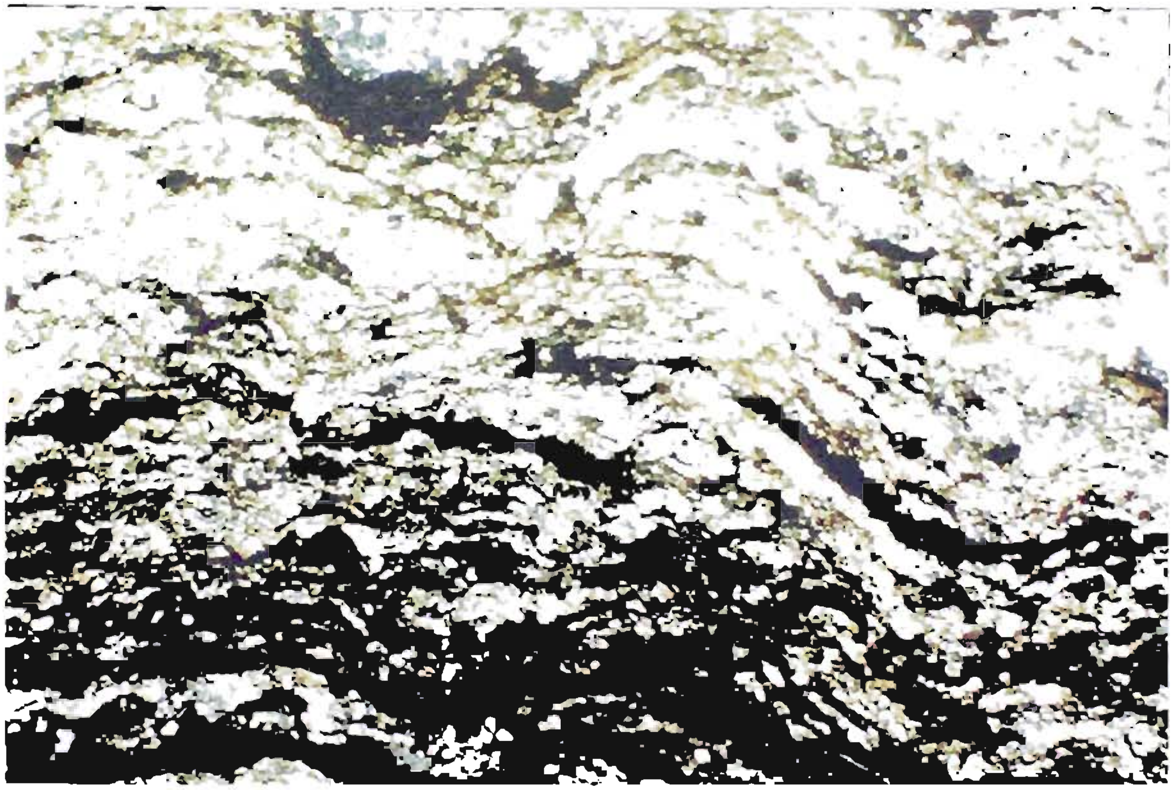
Syndepositional monocrystalline and polycrystalline quartz occur as silt-sized grains and larger (0.1-0.5 mm) grains (Figure 45, bottom). Detrital quartz may be the result of storm deposits, and the source of the polycrystalline quartz was probably pegmatitic.

Diagenetic Imprints

Dolomite

Dolomitization is the principal diagenetic overprint in rocks of the Henryhouse Formation and Chimneyhill Subgroup. Three distinct types of dolomite were observed in the Apexco Green No. 1 Core, namely early, hypersaline dolomite; mixed-water dolomite; and late, thermal dolomite.

Hypersaline dolomite rhombs appear dirty brown (Figure 46, top). The size of the rhombs ranges from 0.01 to 0.1 mm, with the majority of the rhombs falling between 0.025 to 0.05 mm. The dolomite texture ranges from rare idiotopic to the more common



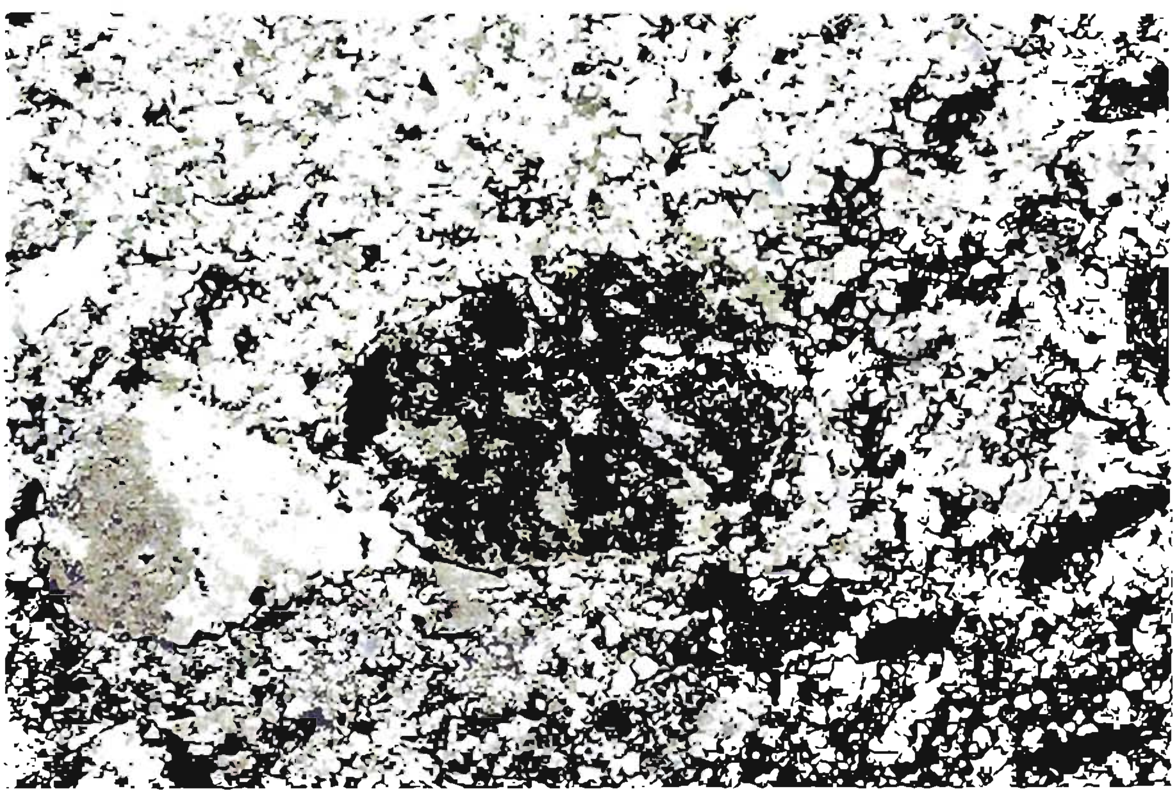


Figure 44. Top photomicrograph: Algal laminations. Apexco Green No. 1. Depth 19,646 feet. 100X, XN. Bottom photomicrograph: Phosphatized echinoderm in a dolomite matrix. Apexco Green No. 1. Depth 19,646 feet. 40X, XN.

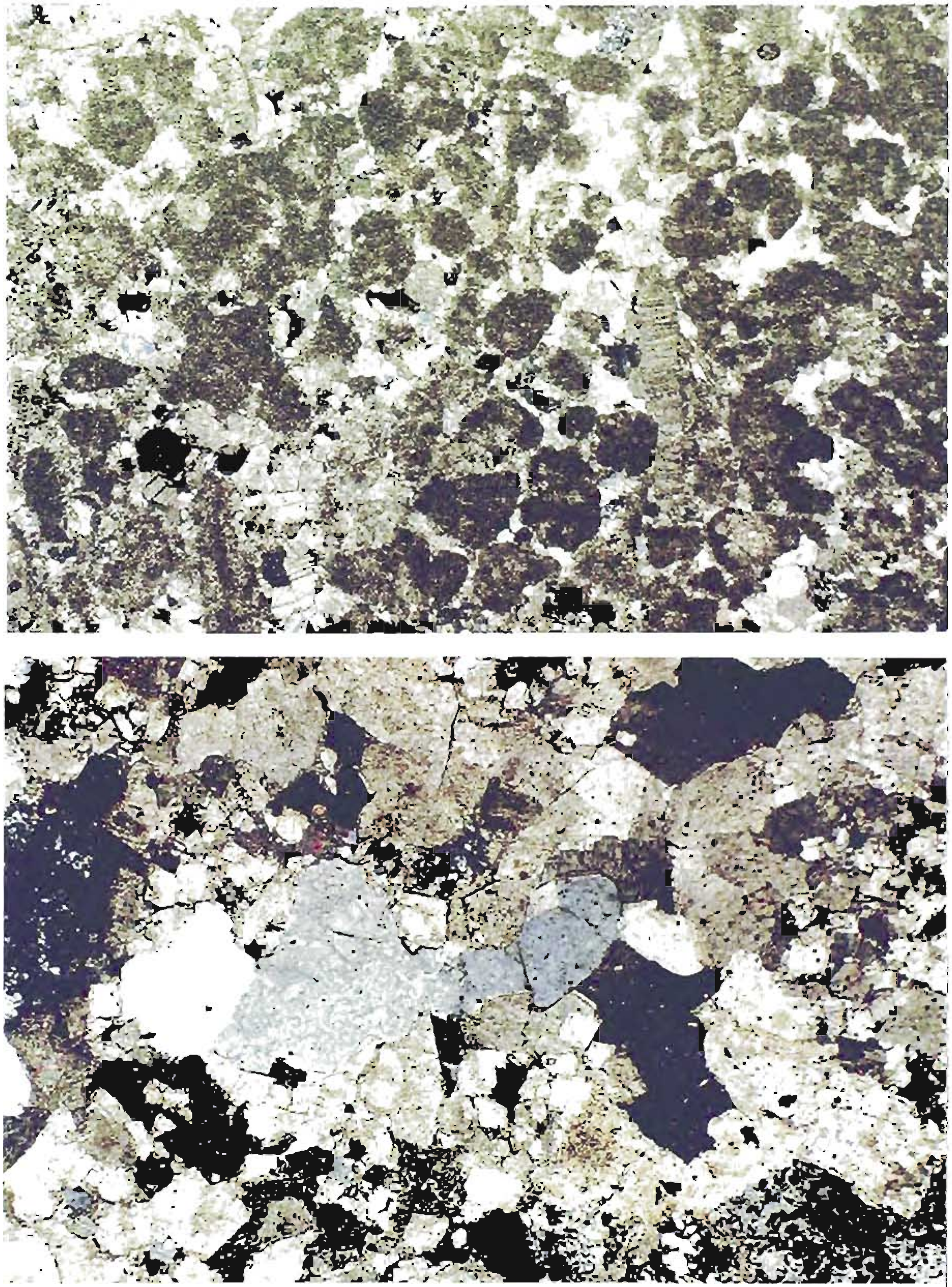


Figure 45. Top photomicrograph: Micritic peloids, most probably of fecal origin, in the intertidal facies. Apexco Green No. 1. Depth 19,733 feet. 40X, XN. Bottom photomicrograph: Detrital quartz. Apexco Green No. 1. Depth 19,702 feet. 100X, XN.

Figure 46. Top: Very fine grained hypersaline dolomite rhombs. Apexco Green No. 1. Depth 19,687 feet. 100X, XN. Bottom: Idiotopic, mixed-water dolomite rhombs in a micritic matrix. Note cloudy center with white (limpid) rim. Apexco Green No. 1. Depth 19,624 feet. 100X, PPL

xenotopic and hypidiotopic. Extinction is straight, indicating a nonthermal origin.

Dolomite of mixed-water origin can be classified into two groups based on rhomb size. Finely crystalline rhombs (0.02-0.05 mm) are interpreted as early precipitation onto micrite and are thus termed dolomicrite. The second type of mixed-water dolomite possesses crystals which are noticeably larger than those described above, with an average crystal (rhomb) diameter of 0.1-0.25 mm. Texturally, this type of dolomite is characterized by idiotopic crystals floating in a micritic matrix (Figure 46, bottom) or loosely interlocking hypidiotopic/idiotopic rhombs (Figure 47). Rhombs commonly possess a cloudy center with white or clear (limpid) outer rims (Figure 46, bottom), although completely limpid rhombs do occur.

The final stage of dolomitization in Henryhouse and Chimneyhill rocks is represented by white, cloudy, void-filling baroque or saddle dolomite (Figure 48). Saddle dolomite crystals typically range in length from 0.5 to 1.5 mm. The distorted crystal lattice and curved crystal faces are associated with curved cleavage traces and sweeping (undulose) extinction. The vug-filling saddle dolomite is a relatively deep-burial, late-stage diagenetic mineral. Radke and Mathis (1980) speculate that it forms at temperatures greater than 80 degrees centigrade, implying a deep-burial origin. This is supported by the fact that the drilling depth of the Apexco Green No. 1 well is in excess of 20,000 ft.

Calcite

Calcite cement can be found infilling fenestral porosity (Figure 49). Calcite spar is a late cement typically formed following exposure of the system to meteoric

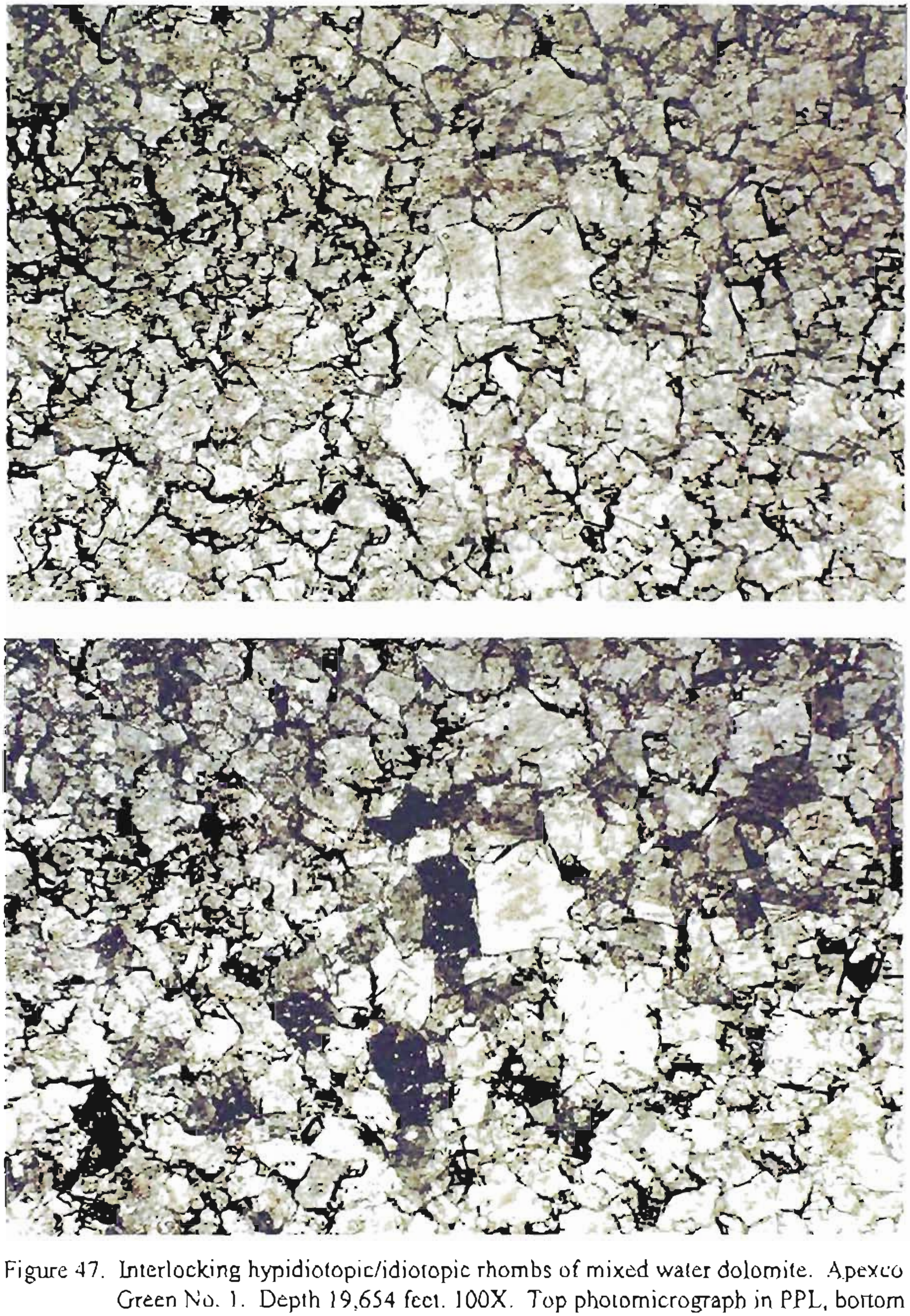


Figure 47. Interlocking hypidiotopic/idiotopic rhombs of mixed water dolomite. Apexco Green No. 1. Depth 19,654 feet. 100X. Top photomicrograph in PPL, bottom photomicrograph in XN.

Figure 48. Void-filling saddle or baroque dolomite. Apexco Green No. 1. Depth 19,708 feet. 100X, XN.

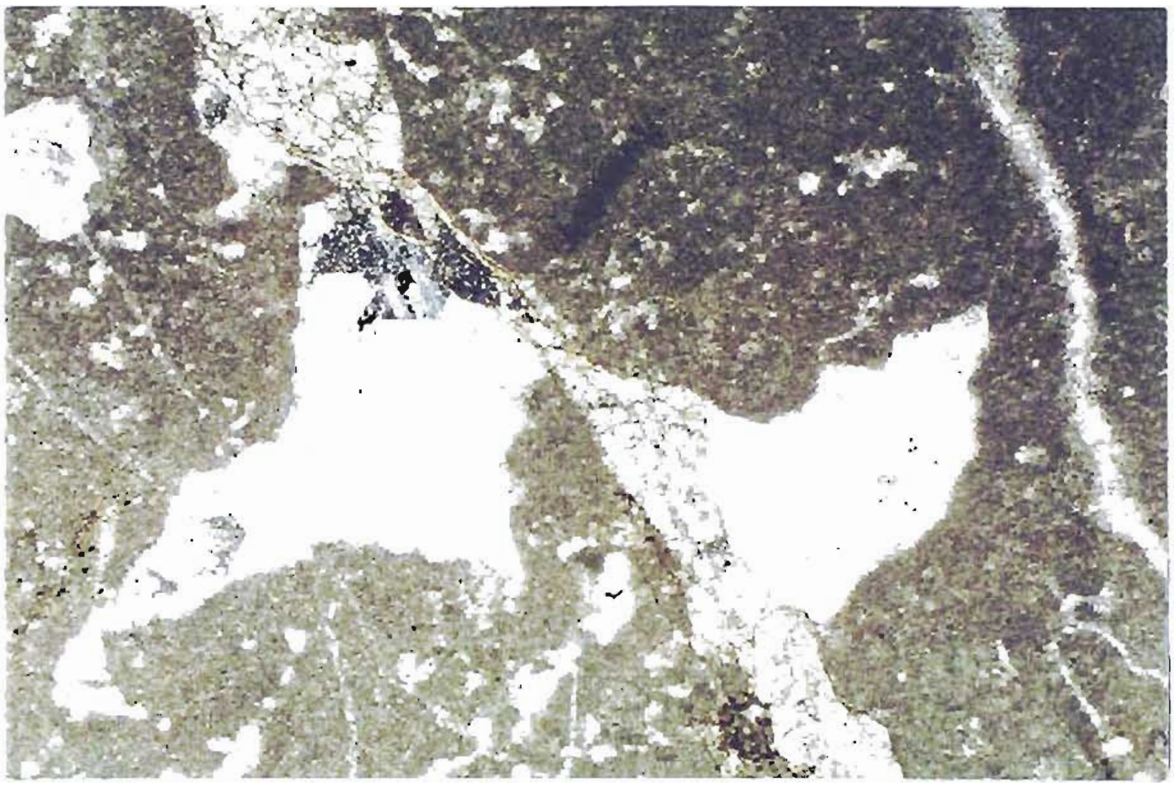


Figure 49. Fenestral porosity in lime mudstone obliterated by calcite spar. Apexco Green No. 1. Depth 19,602 feet. 40X, PPL.

water. Extremely late (post-dolomitization) calcite cement is found infilling interrhombic porosity (Figure 50).

Silica

Authigenic silica occurs in three main forms: (1) void-filling authigenic quartz, (2) chert replacement of dolomite, and (3) chalcedony. Void-filling authigenic quartz is common in the lower zones of the Chimneyhill Subgroup. It appears as clean, white, grains which take on the shape of the void which it is infilling.

At some point following the diagenetic development of dolomite, a silica-rich fluid percolated through the rock. This resulted in the corrosion and subsequent replacement of pore-filling saddle dolomite by chert (Figure 51, top). Radial chalcedony, which is much less abundant than chert, formed in a similar manner (Figure 51, bottom).

Porosity

Secondary porosity is the sole manifestation of destructive diagenesis. First classified by Choquette and Pray (1971), porosity in carbonate rocks is either fabric selective or nonfabric selective. In the Apexco Green No. 1 well, two types of fabric selective porosity were observed: (1) moldic and (2) intercrystalline or interrhombic. Moldic porosity is caused by the dissolution of fossil grains, especially crinoid and mollusk fragments. Molds subsequently may be filled by late baroque dolomite or calcite.

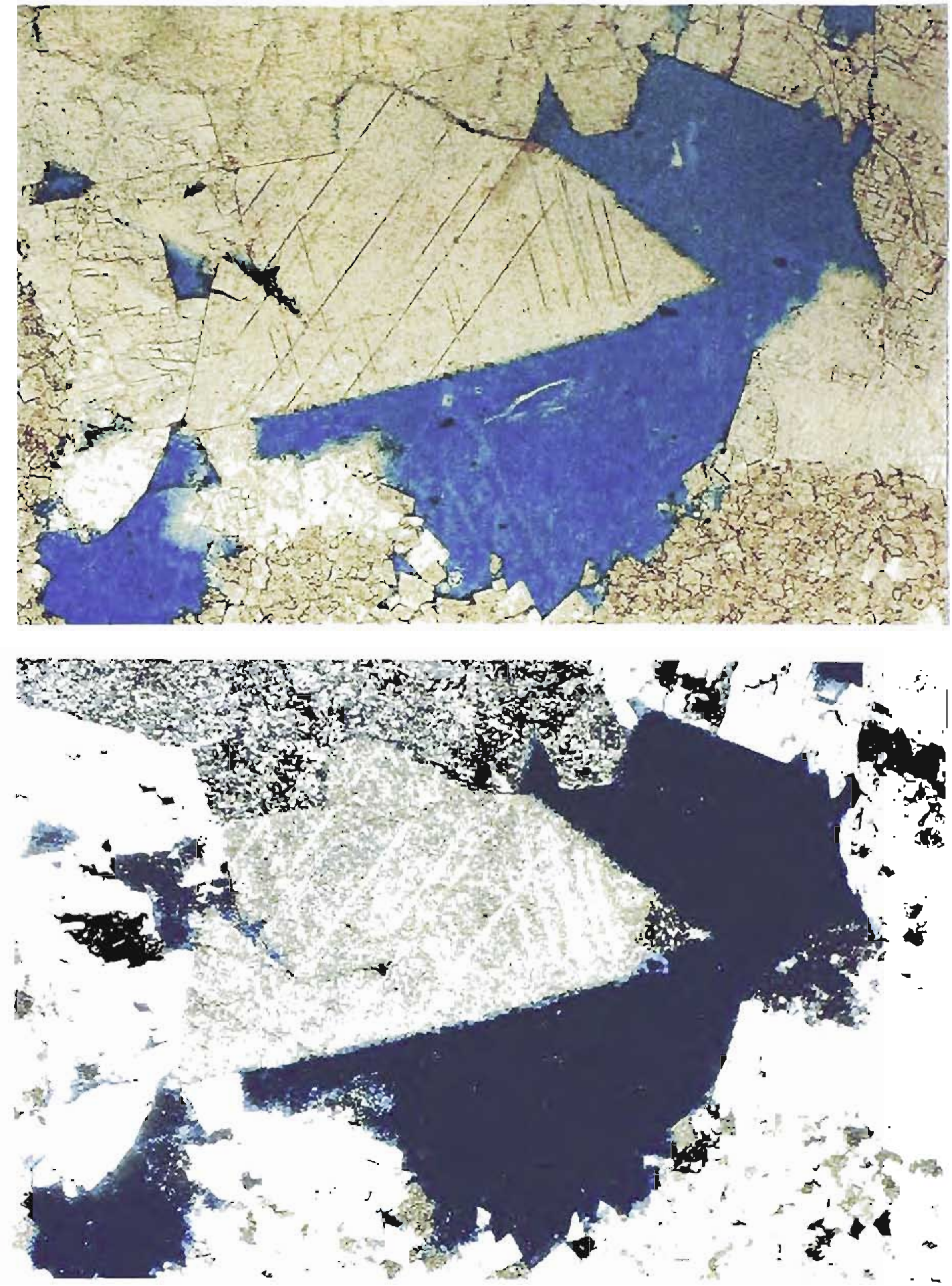


Figure 50. Extremely late (post-dolomitization) calcite cement partially infilling interrhombic porosity. Apexco Green No. 1. Depth 19,770 feet. 40X. Top photomicrograph in PPL, bottom photomicrograph in XN.

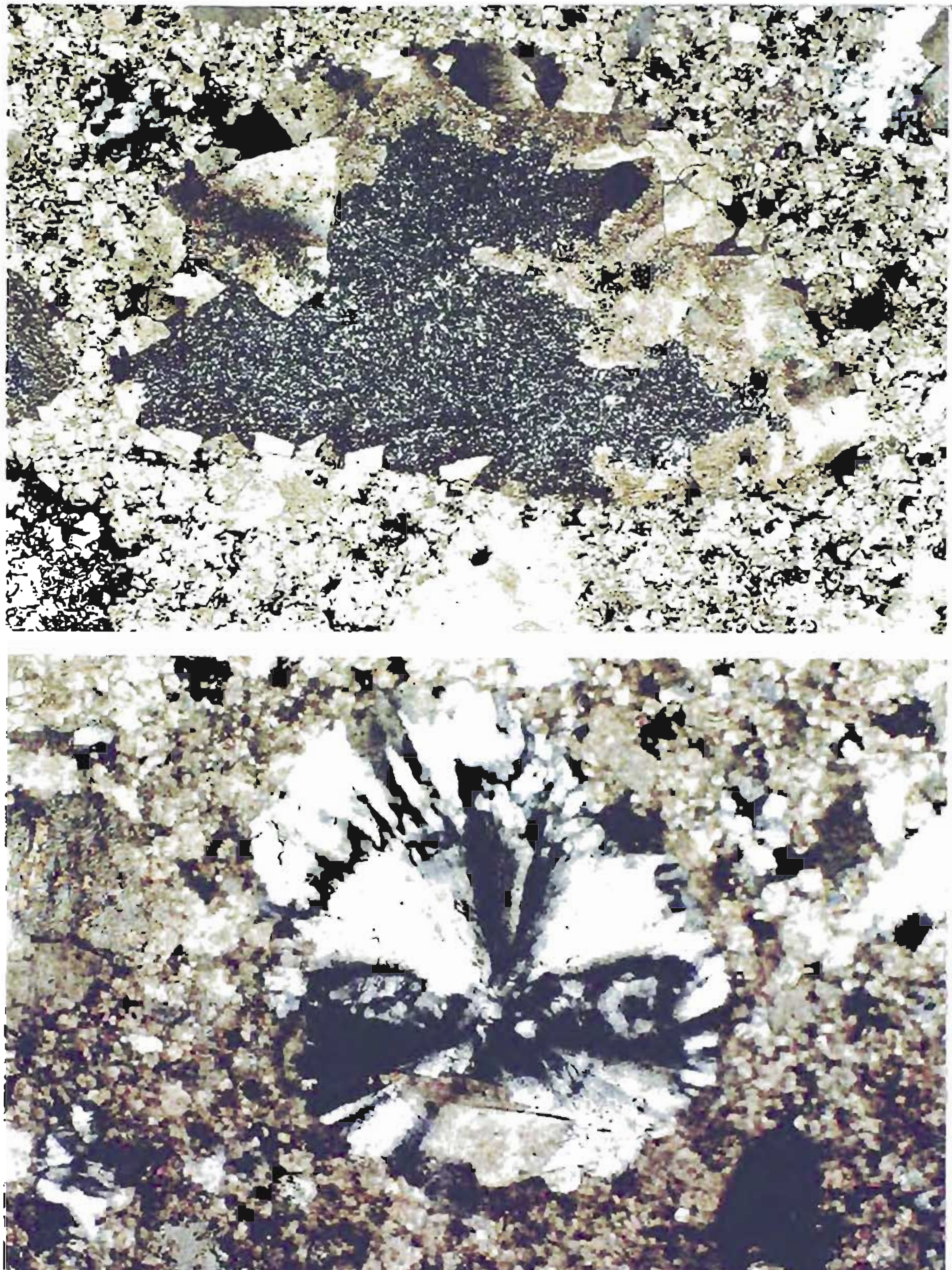


Figure 51. Top photomicrograph: Corrosion of pore-filling baroque or saddle dolomite by chert. Apexco Green No. 1. Depth 19,702 feet. 40X, XN. Bottom photomicrograph: Radial chalcedony (authigenic fibrous silica). Apexco Green No. 1. Depth 19,702 feet, 100X, XN.

Intercrystalline porosity is most commonly found between rhombs of idiotopic to hypidiotopic dolomite (Figure 52). Another scenario for the development of involves the dissolution of nondolomitized calcite matrix.

Vuggy porosity is the sole nonfabric selective porosity type. Vugular pores are solution enlarged molds where the original fossil outline has been destroyed (Figure 53). Dissolution of fossils within the less densely burrowed intervals was the most significant mechanism in development of moldic or enlarged moldic (vuggy) porosity.

Depositional environment plays a major role in the genesis of porosity. Both core and thin section examination reveal the preferential development of porosity in intertidal rocks. Intertidal carbonates are characterized by intense burrowing and fossil debris. Burrowing enhances permeability by redistributing the finer particles, allowing subsequent dissolution of nondolomitized matrix and grains by percolating low-pH solutions. However, the resultant, patchy, irregular porosity is often poorly developed because of cementation by sparry calcite (Al-Shaieb and others, 1993c).

Pressure-Induced Dissolution Features

Stylolites formed by differential vertical movement under pressure accompanied by solution (Figure 54). The seam is characterized by a concentration of insoluble constituents of the rock, namely carbon (organic matter) or iron oxides.

Karstification

Exposure of the Henryhouse and Chimneyhill resulted in karstification. Early dissolution created fractures which were infilled by silt (Figure 55). Fracturing is the sole

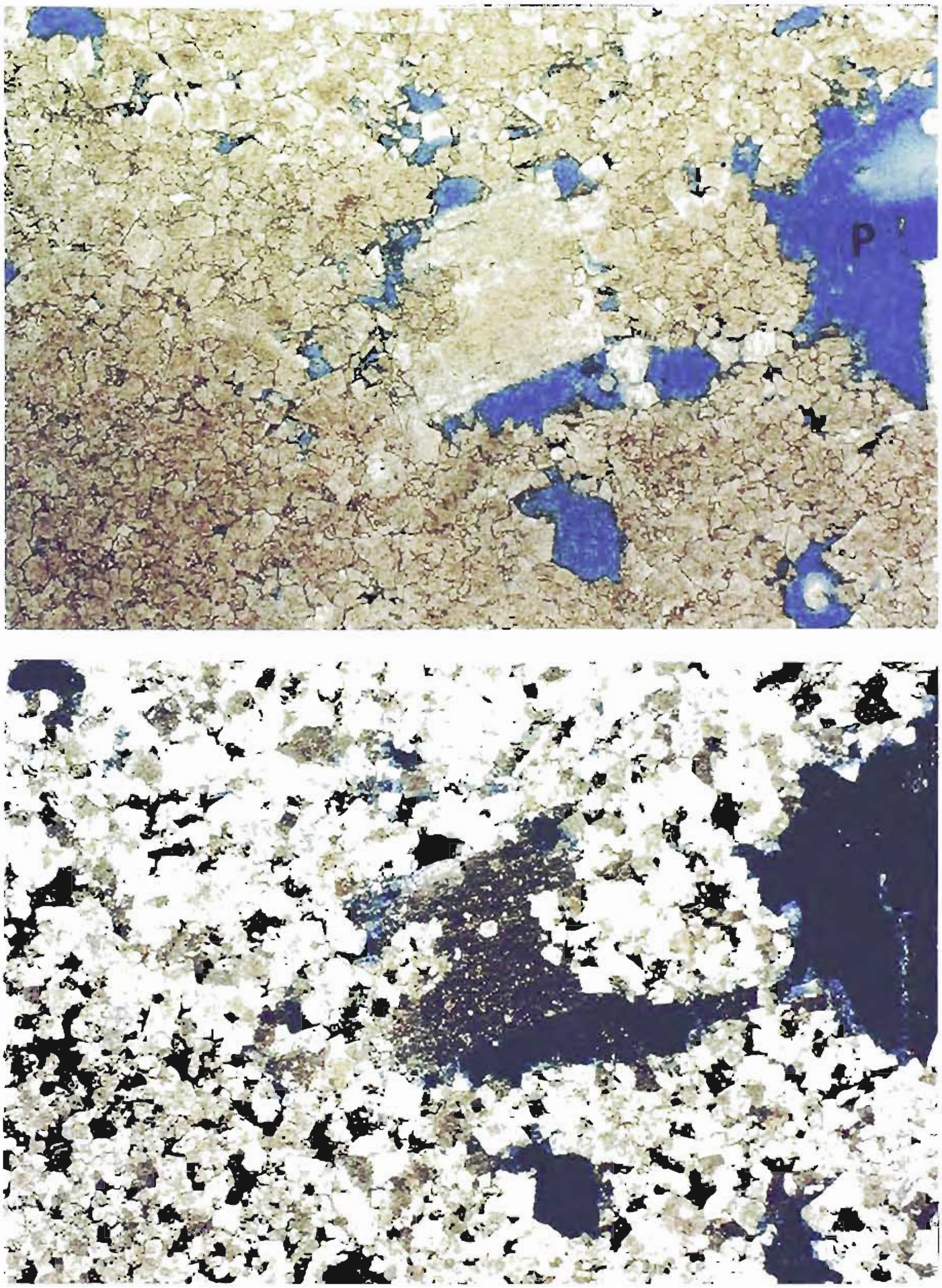


Figure 52. Vuggy porosity (blue) preserved in the intertidal facies. Porosity has been partially infilled by late, baroque or saddle dolomite. Apexco Green No. 1. Depth 19,770 feet. 40X. Top photomicrograph in PPL, bottom photomicrograph in XN.

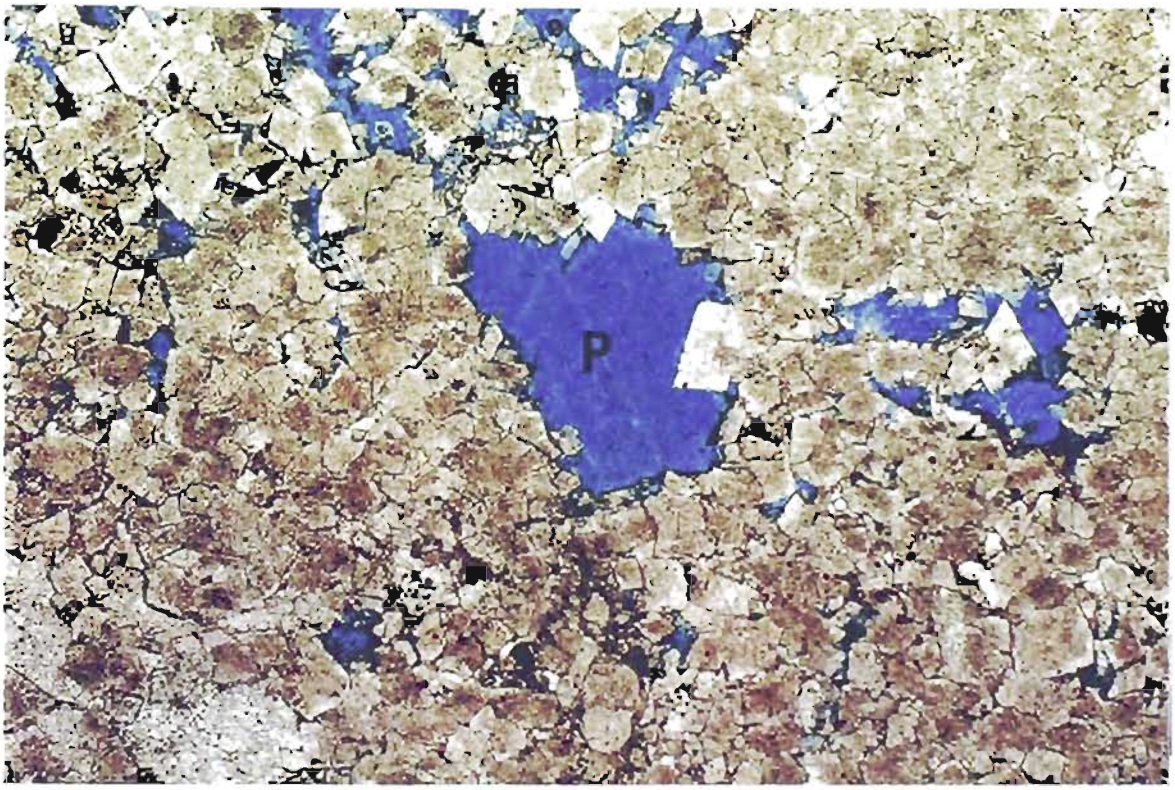


Figure 53. Vuggy porosity (blue) generated from the enlargement of molds. Apexco Green No. 1. Depth 20,231 feet. 40X, PPL.

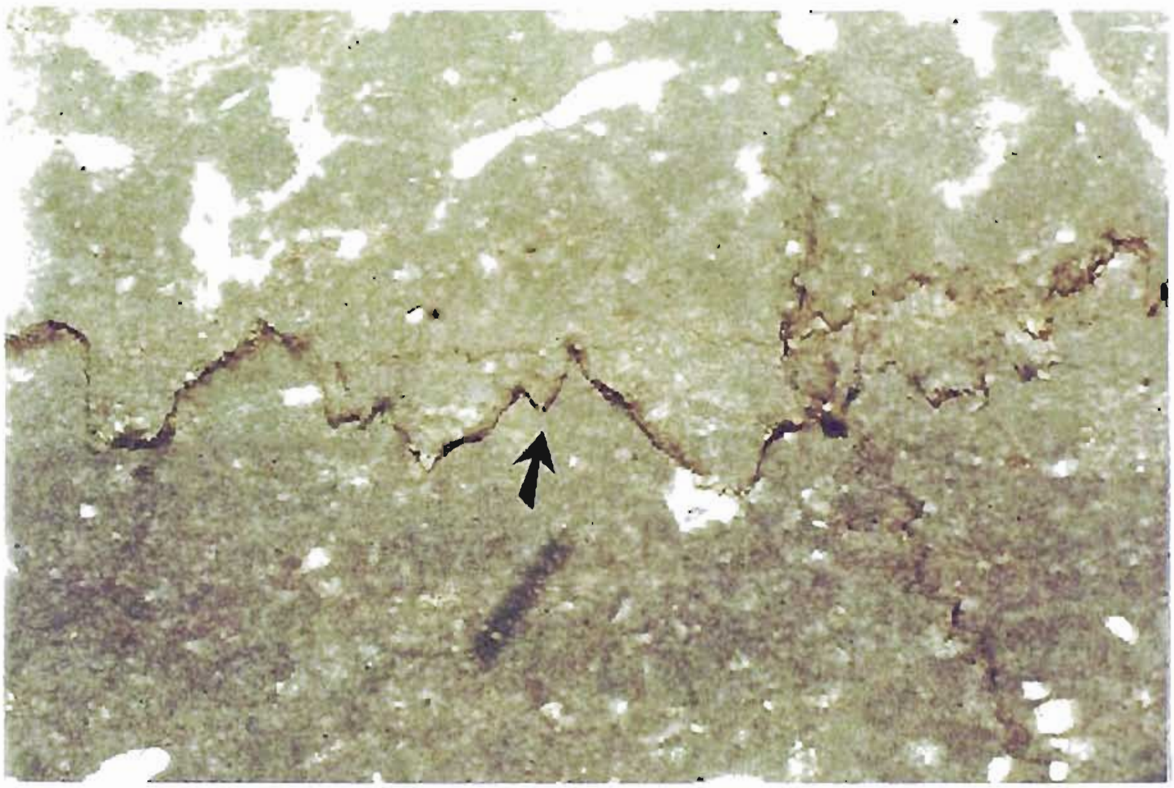


Figure 54. Pressure-induced stylolite with insoluble residue. Apexco Green No. 1.
Depth 19,723 feet. 40X, XN.

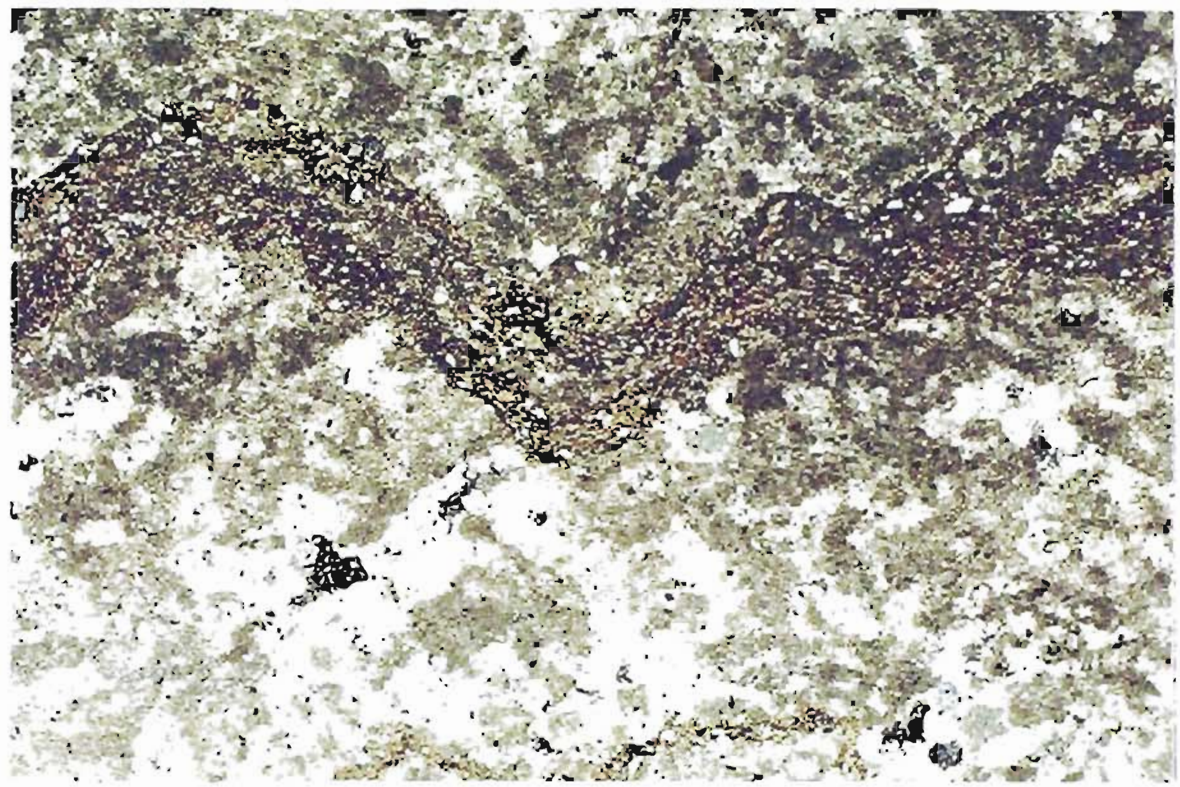


Figure 55. Dissolution fracture (early-stage paleokarst) which was subsequently infilled by silt. Apexco Green No. 1. Depth 19,740 feet. 40X, XN.

indication of paleokarst present in the Apexco Green No. 1 core, implying the rocks were not subjected to large-scale dissolution.

CHAPTER VII

CORE DESCRIPTIONS

Cores from wells drilled the vicinity of the Wichita frontal fault zone were analyzed to determine the nature of the rocks which form the lateral seal. Highly cemented rocks, within the overpressured interval, were compared to those in the normally pressured zones above and below the MCC. Examined cores included overpressured chert conglomerate and "granite wash" reservoirs, and normally pressured clastic and carbonate reservoirs.

Core examination corroborated many of the petrographic observations made in the previous chapter. In the vicinity of the Wichita frontal fault zone overpressured rocks within the MCC are tightly cemented, while normally pressured rocks above and below the MCC are unaffected by this intense fault-associated cementation.

Description of Cores Above the Overpressured Interval (MCC)

Wireline log signatures indicate that most reservoir rocks above the MCC are relatively porous and permeable. The Shell Whitledge No. 1-8 in Sec. 8, T.9N., R.22W., Beckham County, Oklahoma, and the Exxon Felton No. 1-6 in Sec. 7, T.10N., R.22W., Beckham County, Oklahoma, are representative of the normally pressured interval above the MCC. The Shell Whitledge core was examined between 8503 and 8550 feet, and the

Exxon Felton core was investigated between 12,927 and 12,946 feet and 13,092 and 13,105 feet.

Shell Whitledge No. 1-8

The Shell Whitledge contains Missourian/Upper Desmoinesian "granite wash" sediments. The petrologic log found in Appendix A gives a detailed account of the lithology, sedimentary structures, grain size, porosity, detrital and diagenetic constituents found in the core.

The base of the core (8550-8535 feet) is poorly sorted and consists of granophyre cobbles in a very coarse sandstone matrix. The well rounded pebbles and cobbles are generally light gray and cream and have a maximum diameter of 12 cm. Visible porosity is apparent in this region (Figure 56). No recognizable bedding features are found in this interval. The grain size decreases (fines) upward to form a gradual contact with the overlying sandstone.

The interval from 8535 to 8531.5 feet is composed of interstratified fine to very coarse-grained sandstone. Soft-sediment deformation features including flowage and convolute bedding are found in the finer-grained sediments.

From 8531.5 to 8531 is a dark gray shaly interval. Soft sediment deformation features (flowage) are apparent. Immediately above the shale (8531-8529.5 feet) is a tan to buff colored sandstone. Soft sediment deformation features indicate penecontemporaneous deformation.

A six inch band of dark gray shale lies between 8529.5 and 8529 feet. The shale is overlain by an interstratified fine to very coarse grained sandstone from 8529 to 8524

Figure 56. Porous region above the MCC. Arrow identifies enlarged intergranular porosity. Shell, Whitledge No.1-8, Beckham County, Oklahoma. Depth 8542 feet. Scale is in inches.

feet. Soft sediment deformation features including flowage and convolute bedding are found in the finer grained sediments. A dark gray to black shale is found from 8524 to 8521.5 feet. Immediately above the shale is an interstratified fine to very coarse-grained sandstone. The sandstone generally coarsens upward until 8519 feet. From 8519 to 8515 feet, a fine-grained sandstone matrix supports numerous granophyre pebbles. From 8515 to 8514, coarse- to very coarse-grained sandstone clasts are found in a dark gray, shaly matrix.

The next interval (8514-8508 feet) is composed of interstratified silty to very coarse-grained sandstone layers. Flowage features are found in the fine sediments and small scale cross bedding is found in the sandstone intervals.

The uppermost interval from 8508 to 8503 feet is a relatively massive fine-grained sandstone which is generally well sorted and light gray in color. A three inch band of coarse sandstone is found at the 8505 mark, and an eight inch band of coarse sandstone is located at 8505 feet. These coarse-grained zones exhibit sharp contacts with the surrounding fine-grained sandstones.

Conglomerate, sandstone, and shale lithofacies in the cored interval appear to reflect cyclic sedimentation associated with the fan delta environment. The lower cored interval (8550 to 8531.5 feet) reflects a classic channel sequence. Rapid deposition by channelized flow gave rise to a poorly sorted conglomeratic sequence. Waning flow resulted in the infiltration of a finer grained matrix and an overall fining upward sequence.

Braided channel flow is characteristic of the mid fan region. These distributary channels are not as deep or wide as the main channel. They are sites of rapid sedimentation as channels fill during the course of gradual lateral migration or abrupt abandonment. A series of braided stream deposits are found in the upper cored interval. These are readily identified by the alternating bands of fine and coarse sediment. Finer grained intervals may represent an overall decrease in the energy of the system. Conversely, they may reflect splay deposits from the main stream.

Exxon Felton No. 1-6

The Exxon, Felton No. 1-6 core contains Desmoinesian "granite wash" sediments of a much finer grain size than those of the Shell Whitledge core. The lower, fine grained cored interval represents a marine facies, while the upper interval is nonmarine. Evidence for a marine depositional environment includes the abundance of dark gray to black shale and the presence of fossils.

The base of the core (13,103-13,101.2 feet) is a gray fine grained sandstone with numerous mud rip up clasts. Dark gray to black laminae of finer grained (shaly) sediments in bands up to 0.25 inch thick are scattered throughout the lower interval.

A dark gray to black fossilferous shale is found between 13,101.2 and 13,100 feet. Directly overlying the shale (13,100-13,095.5 feet) is a silty sandstone unit. This unit is gray to black in color and contains pebble-sized rip up clasts. Soft sediment deformation features are common in this interval. Stylolites, with their characteristic saw-tooth appearance, were also observed.

The interval from 13,095.5 to 13,092 feet is a light gray, fairly well sorted, fine to medium grained sandstone. Sporadic stylolites and isolated pebbles occur in this massive sandstone zone. Parallel laminae occur at the 13,092 and 13,094 foot intervals.

The interval from 13,092 to 12,947 feet is missing.

The next cored interval, from 12,945 to 12,946 feet, is composed of a gray, poorly sorted, subangular to subrounded conglomerate. The pebbles which form the conglomerate are white to gray in color and are generally less than 0.5 inch in diameter. A sharp boundary separates the conglomerate from the overlying shaly unit. Mud rip up clasts are abundant in this unit (12,945-12,945 feet).

From 12,944 to 12,941.2 feet is a dark gray, well sorted, silty sandstone interval. Rip up clasts are found at the 12,943.5 foot mark, and horizontal laminae are common throughout the interval. The overlying interval (12,941.2-12,939.5 feet) consists of a light gray, fine to medium grained sandstone. A return to silty sandstone is evident at 12,939.5 feet. This well sorted zone is dark gray in color.

The silty sandstone coarsens upward into a two foot sandstone interval between 12,938.8 and 12,936.8 feet. This light gray sandstone unit exhibits low level cross stratification and is well sorted. The sandstone interval gradually fines upward into a dark gray silty sandstone (12,936.8-12,935.2 feet).

A scour surface is evident at 12,935.2 feet. Characterized by a 1.5 inch band of pebbles in a medium sandstone matrix, the scour surface indicates an erosional episode. Immediately overlying the scoured surface is a light gray, laminated, fine grained sandstone which gradually coarsens upward into a coarse grained sandstone (12,934.5-12, 927 feet). Medium scale tabular cross stratification and scattered rip up clasts are found in this interval.

Stacked channel flow associated with the distal end of a fan delta resulted in the depositional sequence observed in the Exxon Felton core. Thin fan delta distributary channel deposits are represented by the cross-bedded sandstone intervals. As the delta prograded seaward, dark gray to black shales were deposited in a submarine environment.

Description of Cores Within the Overpressured Interval (MCC)

Wireline log signatures indicate that the vast majority of reservoir rocks within the overpressured MCC are tightly cemented. The Gulf Community Paine No. 1 in Sec. 13, T.10N., R.26W., Beckham County, Oklahoma and the GHK Kennemer No. 1-22 in Sec. 22, T.9N., R.21W., Beckham County, Oklahoma are representative of the overpressured interval within the MCC. Two intervals of the Gulf Community Paine core were analyzed. The shallower unit was examined between 12,336 and 12,385 feet, while the deeper interval was examined between 12,480 and 12,499 feet. The core was investigated between 12,927 and 12,946 feet and 13,092 and 13,105 feet. The GHK Kennemer core was studied between 13,779 and 13,826 feet and 15,007 and 15,408 feet. Detailed petrologic logs are located in Appendix A.

Gulf Community Paine No. 1

The base of the core (12,497-12,491 feet) consists of granule and pebble-sized grains situated in a medium-grained sandstone matrix. This light gray, poorly sorted conglomeratic interval contains numerous soft sediment deformation features, indicating penecontemporaneous deformation. Flowage structures are the most common soft sediment deformation feature. Flasers, discontinuous whisps of dark mud in sandstone, are abundant throughout the interval. Rip up clasts occur sporadically.

From 12,491 feet to the top of the deeper cored interval (12,480 feet) is an interlaminated fine-, medium-, and coarse-grained sandstone. Rip up clasts are a common feature, as are interbeds and flasers of dark gray mud. Soft sediment deformation features include flowage structures, flame structures, and convolute bedding.

The base of the shallower cored interval lies at 12,385 feet. From the base of the core to 12,380 feet is a dark gray, interlaminated very fine to coarse grained sandstone with horizontal or parallel laminations. Mud rip up clasts are abundant throughout the interval. Soft sediment deformation features abound. They include flame structures, flowage features, and convolute laminations.

The next interval from 12,380 feet to 12,369 feet is a poorly sorted, matrix supported conglomerate (Figure 57). The pebble and cobble-sized clasts are of mixed lithology, consisting of granitic rock fragments, chert, and carbonate pebbles derived from the Arbuckle Group. In some cases, the grains have undergone extreme pressure solution resulting in the modification of the grain boundaries. This type of pressure solution is termed sutured-seam solution. Stylolites, another indication of compaction, are abundant. Small bands of muddy sediment are also apparent. This suggests a change in the energy of the system. Soft sediment deformation features (flowage) are present in the finer grained intervals. Crude stratification is the only sedimentary feature recognized in the coarser grained interval.

The unit generally fines upward into a granule-pebble conglomerate between 12,369 and 12,359.5 feet. The granule to pebble sized clasts are light gray in color and subangular to round. An infilled fracture 0.25 inches wide is located at 13,362 feet.

Figure 57. Calcite-cemented zone in pebble conglomerate. Compaction-induced features such as penetrating grain contacts are not abundant. Gulf Community Paine No. 1, Beckham County, Oklahoma. Depth 12,369 feet.

The core continues to fine upward into a fine grained sandstone interval between 12,359.5 and 12,354 feet. This interval is characterized by interlaminated sand and silt (flasers) and mud rip up clasts. Flame structures indicate soft sediment deformation. An increase in the energy of the system resulted in an abrupt increase in grain size. The interval between 12,354 and 12,349.5 feet is a poorly sorted cobble conglomerate. Sutured seam grain contacts are evident.

From 12,349.5 to 12,448 feet is a very fine grained (silty) sandstone. Flowage features are observed in this interval.

The remainder of the cored interval (12,448 -12,336 feet) is a poorly sorted, matrix supported, cobble conglomerate. The grain size of the matrix generally fines upward from granule-pebble-sized clasts to a fine sandstone. Rounded granitic, cherty, and carbonate lithoclasts are often fractured. Some of the larger grains exhibit sutured-seam grain contacts. Silt filled fractures are another indicator of post-depositional stress.

The depositional environment of the Gulf Community Paine core is nearly identical to that of the Shell Whitledge. Alternating conglomerate, sandstone, and shale intervals reflect cyclic sedimentation associated with a fan delta. Rapid deposition by channelized flow produced the poorly sorted conglomeratic sequences. Waning flow resulted in the infiltration of a finer grained matrix and an overall fining upward sequence.

The mid fan region is characterized by braided channel flow. Stacked channel sequences are readily identified by the alternating zones of fine and coarse grained sediment. Finer grained intervals exhibit soft sediment deformation features and may represent an overall decrease in the energy of the system.

GHK Kennemer No. 1-22

The base of the core, 15,048-15,036 feet, is a dark gray marl. Soft sediment deformation features (flowage and convolute bedding) are evident throughout the interval. Horizontal or parallel laminations are common. Burrows and fossil debris (brachiopods) indicate a marine depositional environment. A sharp contact separates this fine grained limy interval from the overlying sandstone unit.

A small, medium gray sandstone interval is found between 15,036 and 15,035 feet. The sandstone is very coarse grained and well sorted. No sedimentary structures were observed in this zone.

The sandstone coarsens upward into a poorly sorted conglomeratic interval (15,035-15,031 feet). The conglomerate is characterized by rounded, cobble sized grains which are gray to cream in color.

The next section, from 15,031 to 15, 025 is a light gray sandstone. Two small conglomerate sequences are found at the base of the sandstone. The sandstone is generally fine grained and lacks any obvious sedimentary strucutures.

From 15,025-15,018 feet is a lime mud (marl). Soft sediment deformation features are the most common sedimentary structure in this particular interval. A fining upward sequence cumulates in a dark gray, shale between 15,018 and 15,017 feet.

The remainder of the core is a well sorted, fine grained sandstone. Four matrix-supported conglomeratic units, each less than six inches thick, are found in this interval. The sandstone is light gray in color and apparently lacks sedimentary structures.

The base of the upper cored interval (13,826-13,819 feet) is a poorly sorted, tan to buff colored conglomerate. It consists of rounded pebbles and cobbles within a calcarenite matrix. Stress-mediated dissolution is evidenced by embayed grain contacts. The conglomerate fines upward into a fairly well sorted, fine to medium grained sandstone (13,819-13,817 feet). The sandstone is buff colored and reacts with dilute hydrochloric acid, indicating calcite.

Immediately overlying the sandstone is a poorly sorted, tan to buff colored conglomeratic unit (13,817-13,812 feet). It is composed of rounded pebbles and cobbles in a fine grained calcarenite matrix.

Another fining upward sequence cumulates in a fine grained sandstone interval. The sandstone, located between 13,812 and 13,808 feet, is well sorted and ranges in color from tan to gray. Sedimentary structures include burrows and horizontal laminae. Sporadic stylolites are found in this zone.

The remainder of the core, from 13,808-13,779 feet, is a dark gray, very fine grained marl. Numerous brachiopod fragments indicate a marine depositional environment. Soft sediment deformation features (flowage) are abundant in this interval. The uppermost eleven feet of core are highly burrowed.

The GHK Kennemer core is located on the edge of the clastic wedge. As a result, two distinct depositional environments are represented. The coarse grained clastic material was shed off of the uplifted block as part of a fan delta system. Episodes of renewed tectonism rejuvenated streams in the source area and produced pulses of sediment influx to the fan. Clastic sedimentation from the uplifted areas alternated with marine sedimentation. During periods of little or no tectonic activity, episodes of marine inundation and carbonate sedimentation dominated the region. This bimodal sediment source resulted in the inter-tonguing of coarse clastic debris and fine grained limy intervals.

Description of Cores Below the Overpressured Interval (MCC)

Apexco Green No. 1-8

Immediately below the MCC, wireline log signatures indicate a return to porous and permeable reservoir rocks. The Apexco Green No. 1-8 core in Sec. 31, T.10N., R.26W., Beckham County, Oklahoma is visibly porous. The core was obtained from the Oklahoma Geological Survey Core Library in Norman, Oklahoma and examined between the following intervals:

1. 19,599-19,626 ft. (Henryhouse Formation)
2. 19,685-19,720 ft. (Henryhouse Formation)
3. 19,765-19,771 ft. (Henryhouse Formation)
4. 20,230-20,261 ft. (Chimneyhill Subgroup)

A complete core petrologic log can be found in Appendix A

The cored interval can be described as a shallowing upward sequence. The upper facies (19,599-19,625 ft. and 19,685-19,720 ft.) is mainly supratidal. Medium gray lime/dolomudstone is the dominant lithology. Fossils are rare or absent, while fenestral fabric, algal laminations, irregular carbonate laminations, and massive fabrics are common. Stylolites are abundant throughout the cored interval. Small-scale sea level fluctuations are represented by intervals of intense burrowing, increased fossil content, and darker coloration. These zones most likely represent shallow water intertidal/upper subtidal facies.

The zone between 19,765 and 19,771 ft. is a burrowed/bioturbated dolomitic mudstone-wackestone. The lowermost three feet is visibly porous, attributable to molds and enlarged molds (vugs). The increase in fossils coupled with intense burrowing indicates an intertidal depositional environment.

The lowermost section (20,230-20,261 ft.) consists of two facies. The upper one (20,230-20,232 ft.) is a burrowed/mottled dolowackestone. Porosity is evident in the form of vugs (Figure 58). The depositional environment was probably intertidal. The interval from 20,233-20,260 ft. is a medium to light gray, burrowed/bioturbated dolomudstone with knobby or hummocky bedding. Chert nodules/zones and stylolites are common. A shallow subtidal depositional environment is indicated by the fossil content and sedimentary structures.

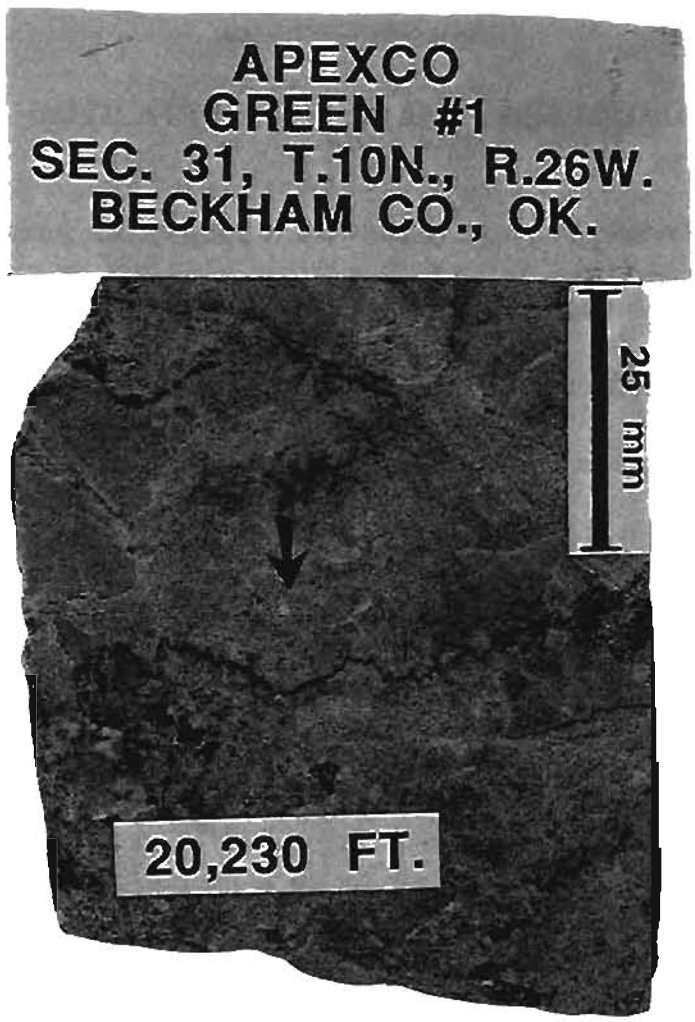


Figure 58. Vuggy porosity (arrow) in normally pressured carbonate rocks below the overpressured MCC. Apexco Green No. 1, Beckham County, Oklahoma. Depth 20,230 feet. Scale is in mm.

CHAPTER VIII

IMPLICATIONS FOR OIL AND GAS EXPLORATION

The stacking and merging of individually cemented intervals created a zone of non- to poorly producing reservoirs in the vicinity of the fault. All reservoirs within the overpressured interval are affected by the cementation phenomenon. Together, the stacked cemented units form a vertical lateral seal along the southern boundary of the MCC that serves to isolate highly overpressured reservoirs in the deep Anadarko Basin. Production potential for overpressured interval reservoirs proximal to the fault zone is significantly reduced, while normally pressured reservoirs above and below the MCC remain relatively unaffected.

Production Maps

Both core and petrographic data from wells drilled in the overpressured interval (MCC) near the Wichita frontal fault zone indicate that the non- to poorly-productive chert conglomerate and "granite wash" intervals are highly cemented. This fault-associated cementing may be divided into two overlapping zones. The first zone is typically 1-2 miles wide and lacks commercial gas reserves. The second zone contains rocks which are locally heavily cemented alternating with porous rocks with higher production potentials.

A production map of upper Morrowan chert conglomerate fields (Figure 59) illustrates the tightly cemented, low porosity fairway immediately adjacent to the Wichita frontal fault zone. Note that there are no fields within several miles of the fault zone. This region corresponds to the lateral seal of the MCC.

On the other hand, a production map of fault-associated Hunton fields shows gas production in the Hunton occurs immediately adjacent to the fault zone (Figure 60). These normally pressured rocks were unaffected by the intense fault-associated cementation and remained porous and permeable.

Production Profiles

Two types of production profiles were constructed in the study area by Al-Shaieb and others (1993c) as part of a Gas Research Institute investigation into the fault-associated cementation in the western Anadarko Basin. Horizontal or planar profiles graphically present the changes in production moving laterally away from the fault. Figure 61 shows the location of cross-sections A-A' and B-B' used in the construction of the horizontal profiles. Vertical profiles illustrate the vertical variability in productivity within a given area.

Horizontal Profiles

Two representative horizontal profiles from the western part of the basin are shown in Figure 62 . Profile A-A' extends from the New Liberty field area in T.10N., R.24W., northward to the West Cheyenne field in T.13N., R.24W. The production curve on this graph shows an abrupt decline in cumulative production of around 10 bcf/well in

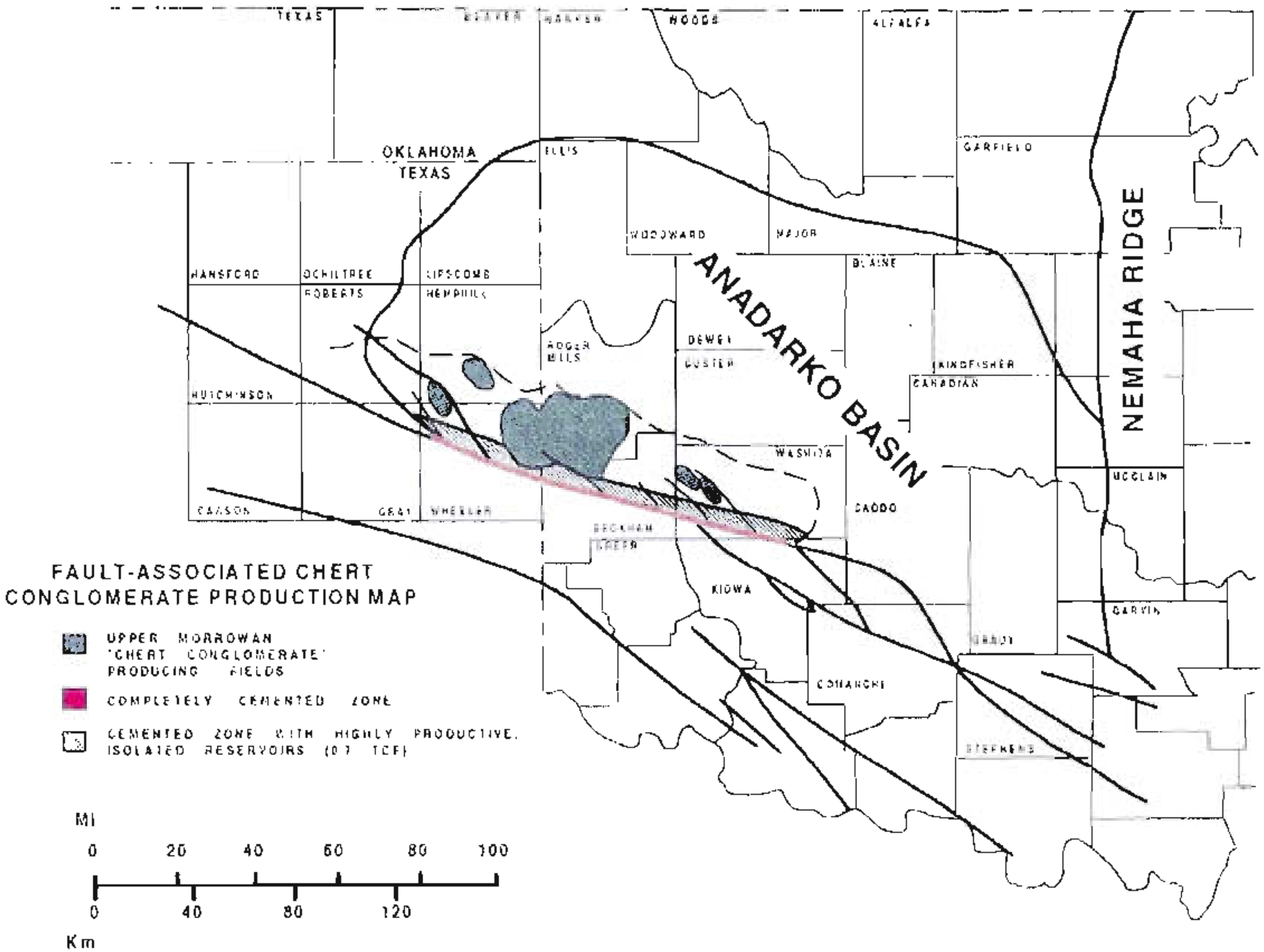


Figure 59. Fault-associated upper Morrowan chert conglomerate production map (after Al-Shaieb and others).

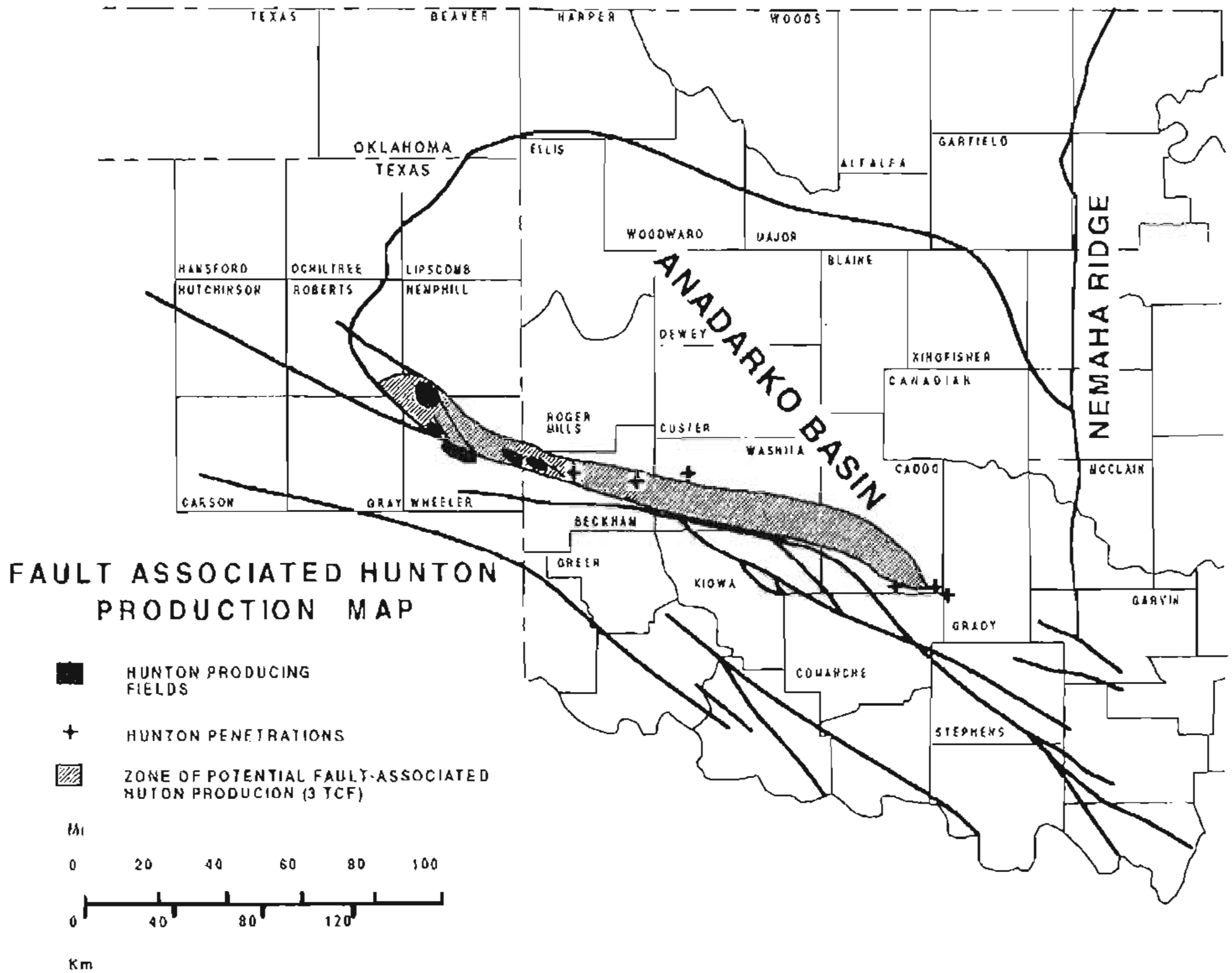


Figure 60. Fault-associated Hunton production map (after Al-Shaieb and others).

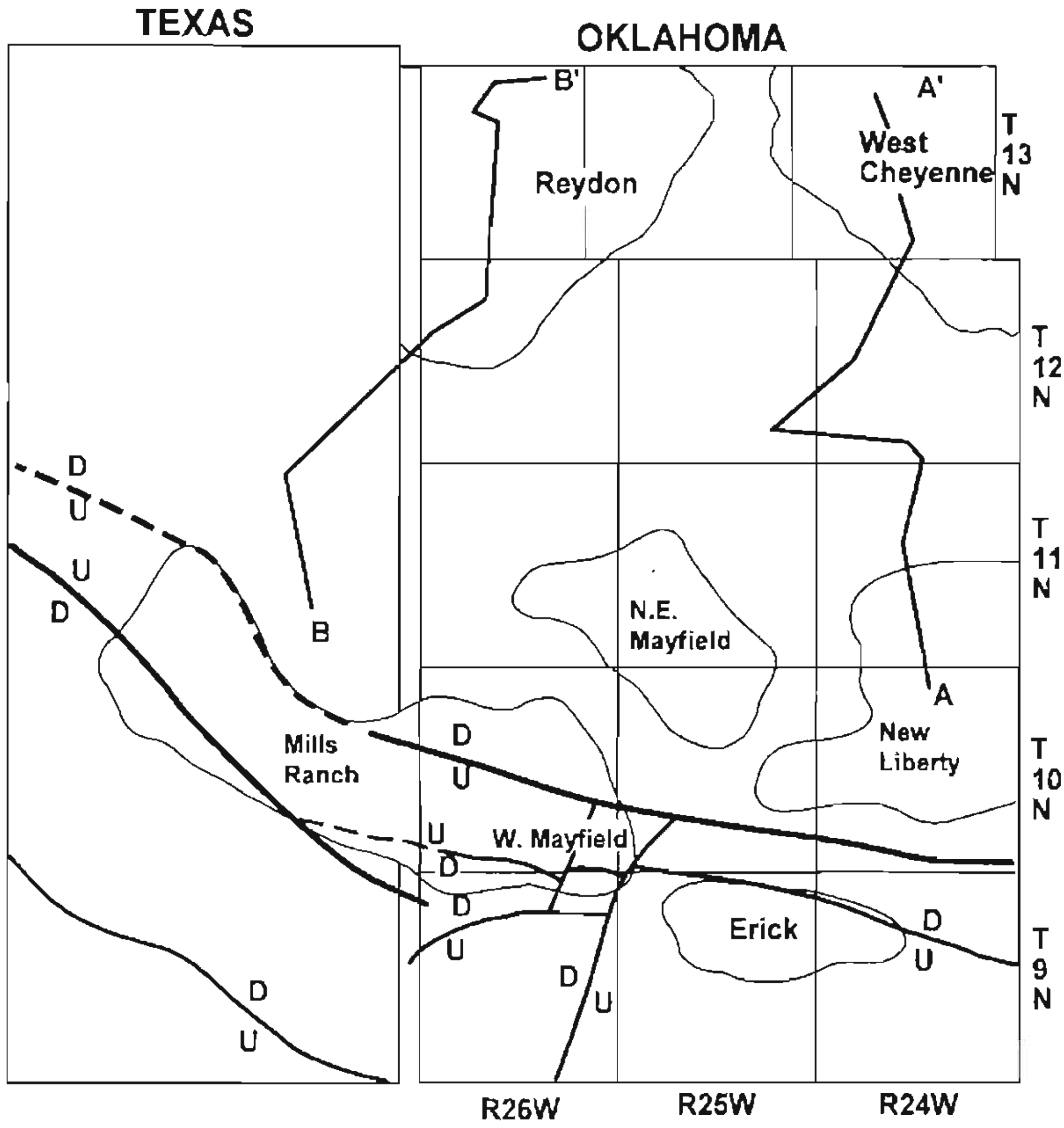


Figure 61. Location of major fields and cross-sections A-A' and B-B' (modified after Al-Shaieb and others, 1993c)

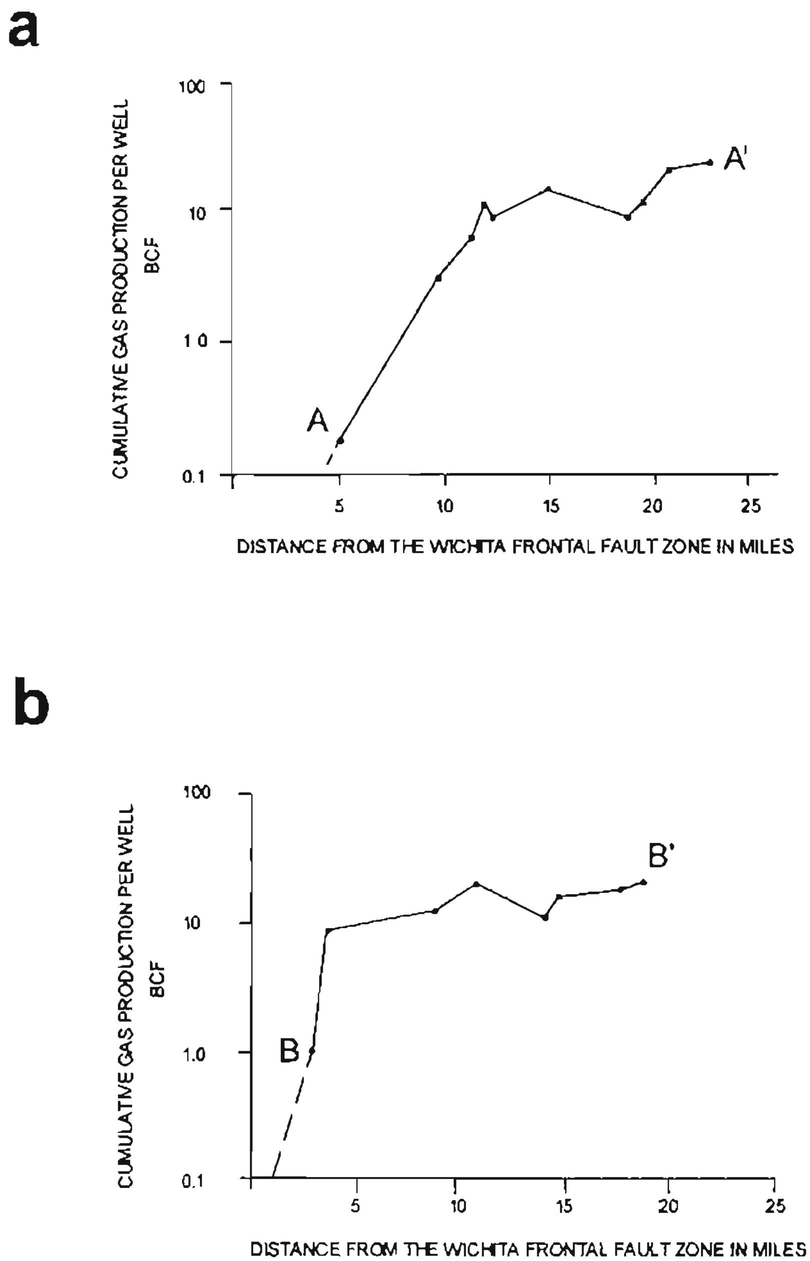


Figure 62. Production profiles illustrating cumulative gas production in bcf per well versus distance from the fault zone in miles. See Figure 61 for location (after Al-Shaieb and others, 1993c).

(a) Profile A-A' from the New Liberty field in Beckham County, Oklahoma, to the West Cheyenne field in Roger Mills County, Oklahoma.

(b) Profile B-B' extending from the Mills Ranch field in Wheeler County, Texas, to the Reydon field in Roger Mills County, Oklahoma.

the West Cheyenne field to less than 0.1 bcf/well in the fault zone vicinity. Profile B-B', which extends from the Mills Ranch field in Block 7, H & G.N. Survey, Wheeler County, Texas, to the Reydon field in T. 13 N., R. 26 W., is similar in nature.

Vertical Profiles

Four vertical profiles were constructed in the western Anadarko Basin. Profile 1 (Figure 63) is from the West Mayfield/Erick area. In this profile, a decrease in production from around 1 bcf/well to 0.1-0.3 bcf/well is apparent across the boundary between the shallow normally pressured interval and the overpressured MCC. Note that the normally pressured rocks below the MCC are also highly productive and have reserves of 8-9 bcf/well. Profile 2 (Figure 64) is from the Mills Ranch field. It is similar to Profile 1 and shows a drastic decline in production across the overpressured interval (MCC). "granite wash" and chert conglomerate cores from this interval identify intense cementation as the cause for the low productivity. Reservoirs both above and below the MCC are apparently porous and highly productive. Profile 3 (Figure 65) is located in the Northeast Mayfield field. In this area, productivity changes across the boundary between normally pressured rocks and the MCC (increases from around 1 up to 3 bcf/well), but no drastic decline in production is evident. Profile 4 (Figure 66) comes from the Reydon and West Cheyenne fields. This profile gives no indication of a production decline in the overpressured interval. These reservoirs located distal to the fault are apparently unaffected by the fault-associated cementing.

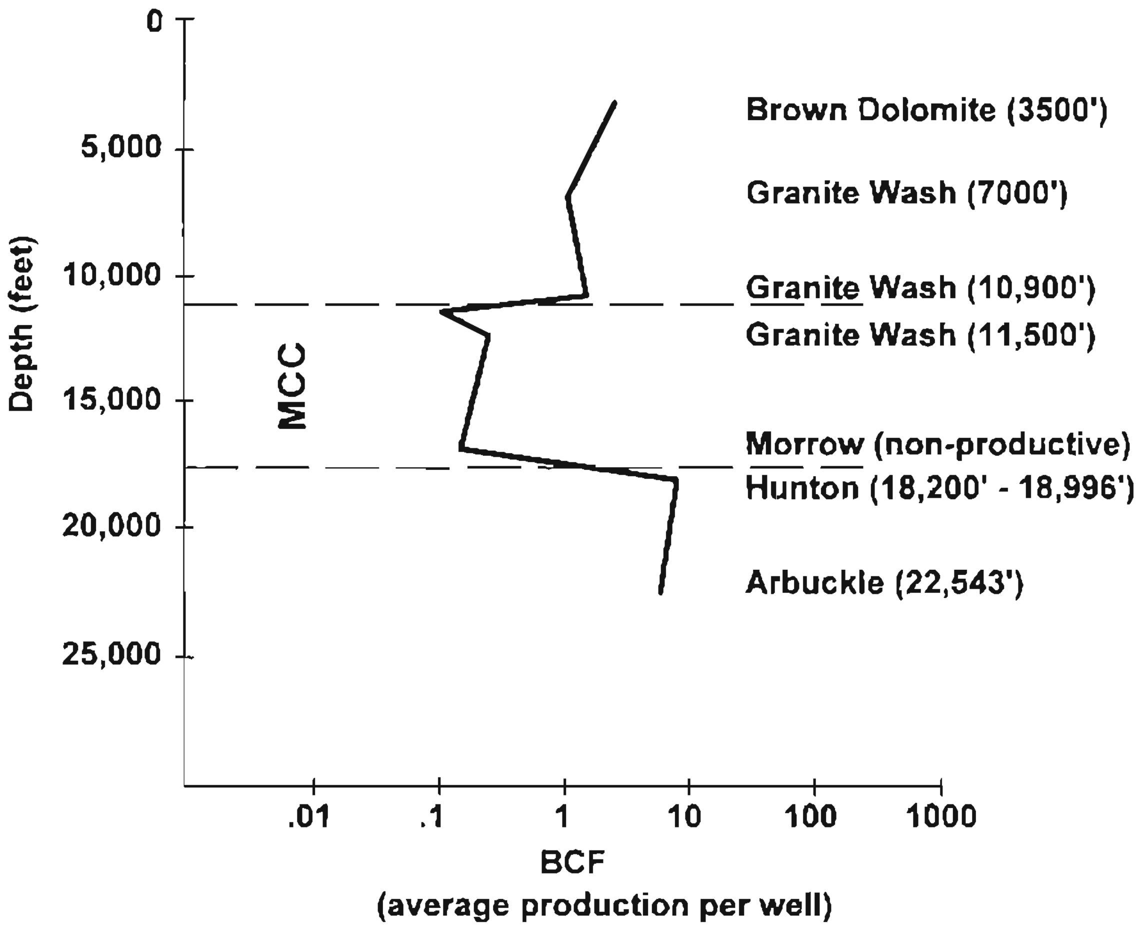


Figure 63. Vertical production profile from the West Mayfield and Erick field areas. Note the drastic reduction for production for wells in the overpressured MCC. Intense cementation in this interval has radically reduced reservoir quality (after Al-Shaieb and others, 1993c).

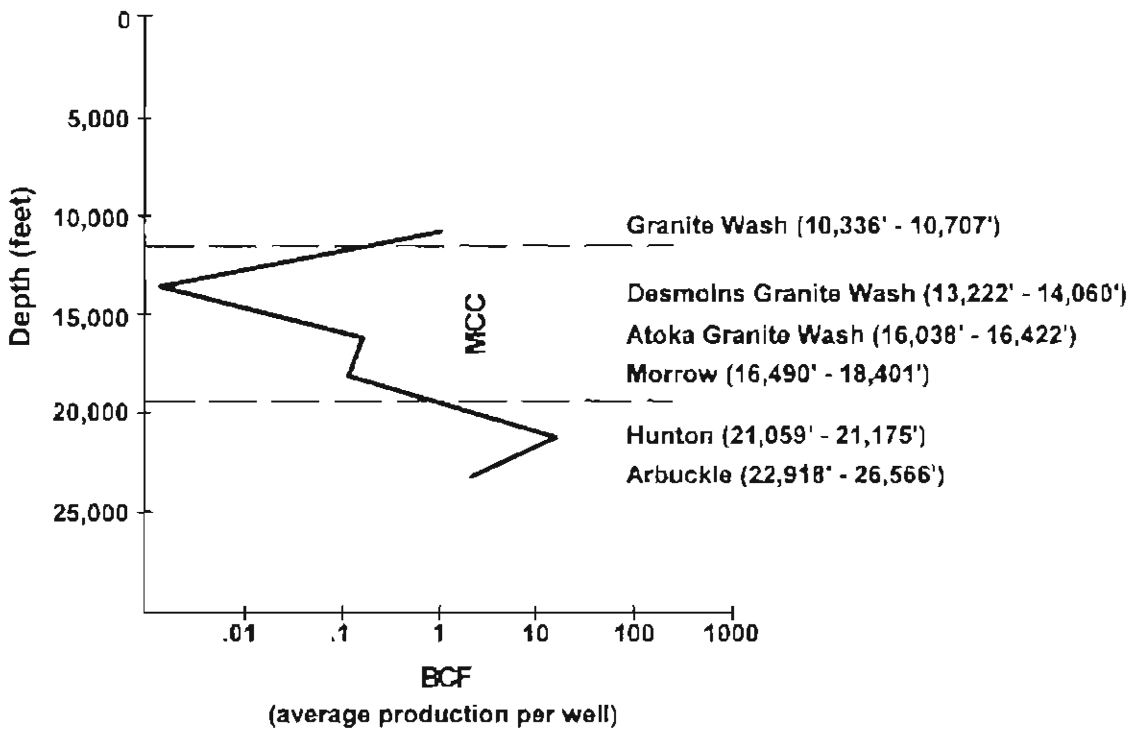


Figure 64. Vertical production profile from the Mills Ranch field. Note the drastic reduction for production for wells in the overpressured MCC. Intense cementation in this interval has radically reduced reservoir quality (after Al-Shaieb and others, 1993c).

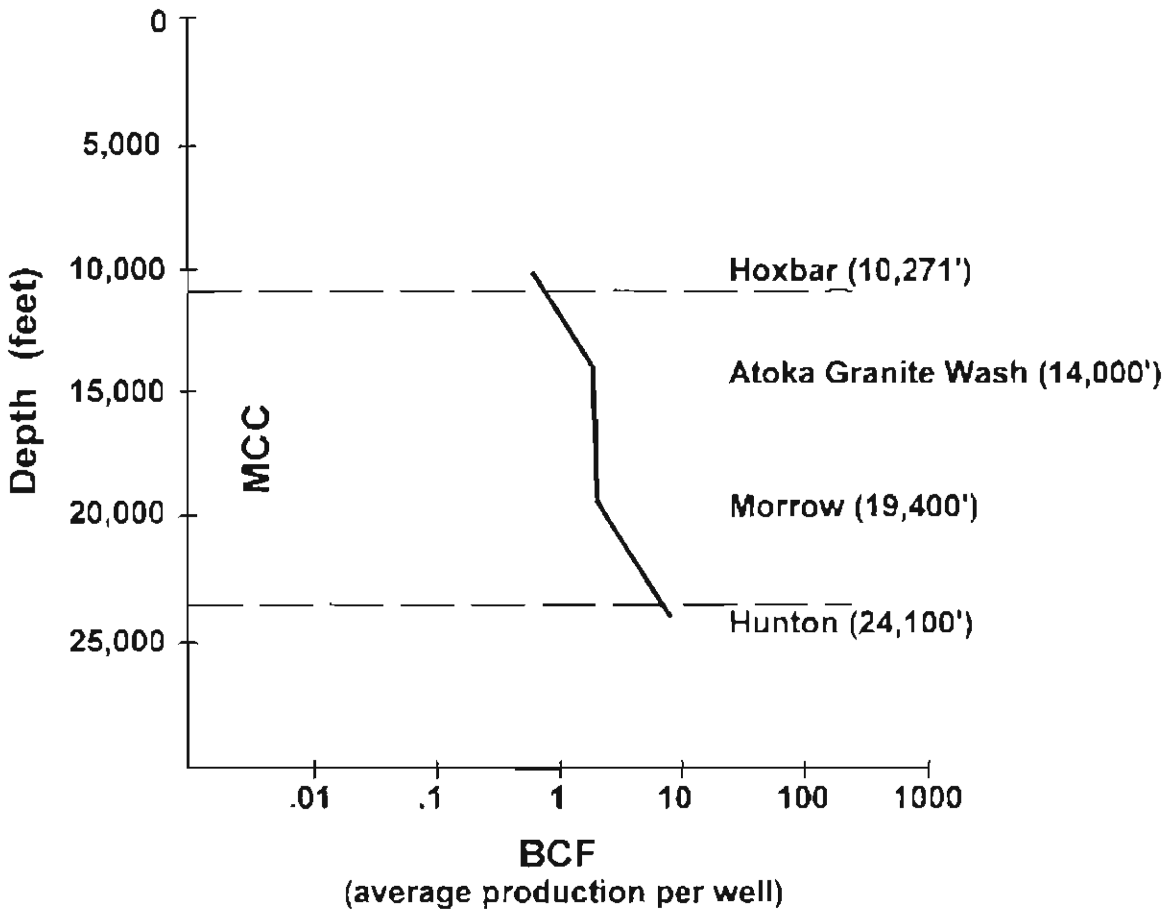


Figure 65. Vertical production profile for the N.E. Mayfield field. This field is distal to the fault, hence the profile shows no significant reduction in productivity within the overpressured MCC (after Al-Shaieb and others, 1993c).

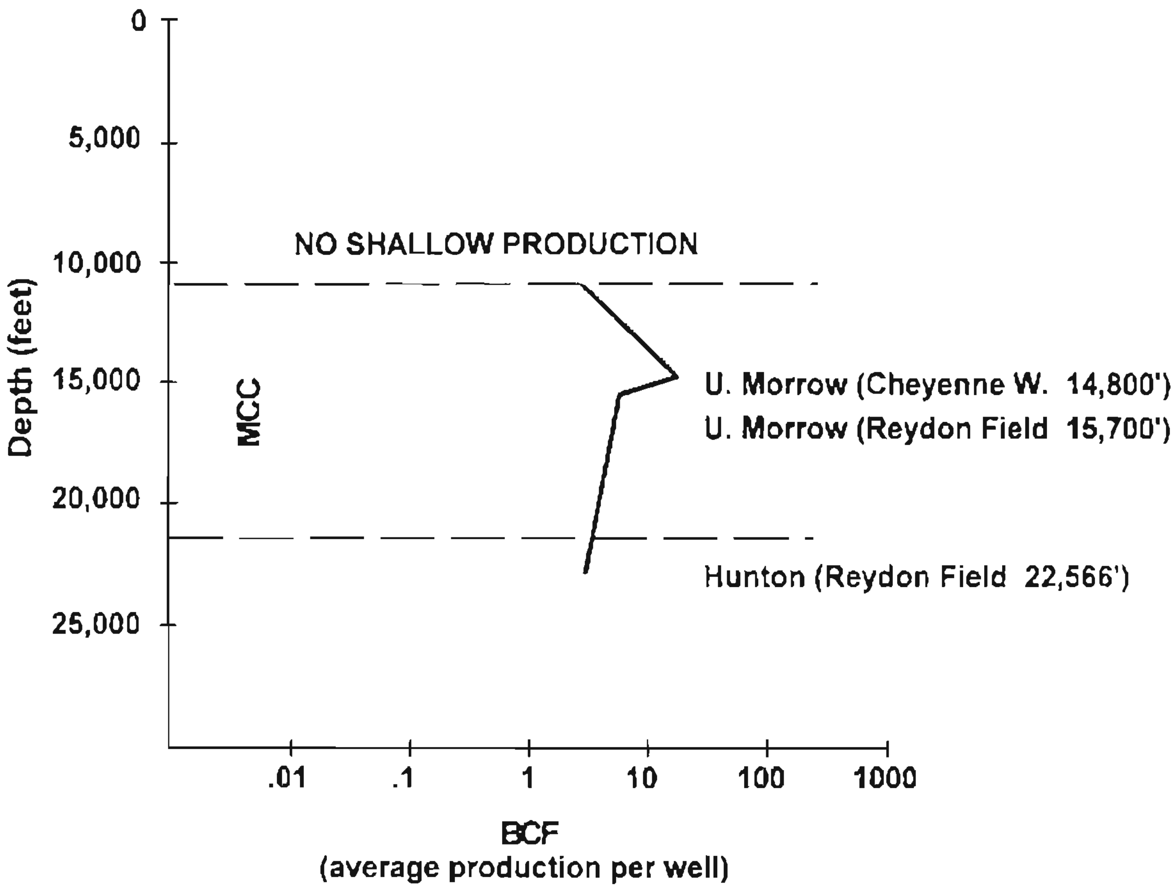


Figure 66. Vertical production profile for the Reydon-West Cheyenne fields. These fields are distal to the Wichita frontal fault zone, and their profiles do not display a drastic reduction in productivity across the overpressured MCC (after Al-Shaieb and others, 1993c).

CHAPTER IX

CONCLUSIONS

After analyzing various aspects of the fault-associated reservoir rocks in the western Anadarko basin, several conclusions were made. These include:

1. Petrophysical and lithologic data reveal that sandstone/conglomerate-dominated rock units within the overpressured interval (MCC) are highly indurated and non- to poorly-productive adjacent to the Wichita frontal fault zone.
2. Distal overpressured and normally pressured clastic and carbonate reservoirs above and below the MCC are relatively unaffected by this intense fault-associated cementation.
3. Sandstone/conglomerate-dominated sequences within the MCC entered the seal window concurrent with displacement along the fault zone. The fault maintained hydrostatic conditions through its continued movement during the middle and upper Pennsylvanian.
4. Reduced pore fluid pressure in the fault vicinity facilitated fluid flow from the overpressured sediment column toward the fault. As a result, solute precipitation and augmented compaction transpired in rocks near the fault zone.
5. Compaction features found in these rocks include sinuous grain contacts and stylolites.

6. Petrographic analysis indicates increased cementation within the overpressured interval reflects framework grain mineralogy and often results in the complete occlusion of porosity by authigenic mineralization. Authigenic minerals include silica in the form of quartz overgrowths and quartz grains in chert-rich rocks and calcite and dolomite in carbonate-rich rocks.
7. Strata above and below the MCC exhibit intergranular and vuggy porosity. These intervals maintained near-normal pressures and were unaffected by fault-associated cementation as no pressure differential existed to drive fluid migration.
8. The cemented interval along the Wichita frontal fault zone forms a low-porosity fairway that functions as the southern lateral seal of the MCC.

References

Adler, F. J., 1971, Future petroleum provinces of the Mid-Continent: future petroleum provinces of the United States, their geology and potentials: American Association of Petroleum Geologists Memoir 15, p. 985-1120.

Alberta, P. L., 1987, Depositional facies analysis and porosity development of the (Pennsylvanian) upper Morrow chert conglomerate "Puryear" member, Roger Mills and Beckham Counties, Oklahoma: unpublished M.S. thesis, Oklahoma State University, 134 p.

Al-Shaieb, Z., 1991, Compartmentation, fluid pressure important in Anadarko exploration: Oil and Gas Journal, v. 89, no. 27, p. 52-56.

Al-Shaieb, Z., Beardall, G., Medlock, P., Lippert, K., Matthews, F., and Manni, F., 1993a, Overview of Hunton facies and reservoirs in the Anadarko Basin, *in* Johnson, K. S. (ed.), Hunton Group core workshop and field trip: Oklahoma Geological Survey Special Publication 93-4, p. 3-39.

Al-Shaieb, Z., Ortoleva, P., 1991, Genesis and dynamics of basin compartments and seals: Supplemental Report to the Gas Research Institute, 57 p.

Al-Shaieb, Z., Ortoleva, P., and Powley, D., 1992a, Three new exploration and development concepts for compartmented basins: Proposal to the Gas Research Institute, 86 p.

Al-Shaieb, Z., Ortoleva, P., and Powley, D., 1993b, Three new exploration and development concepts for compartmented basins: July-October 1993 Quarterly Report to the Gas Research Institute, 162 p.

Al-Shaieb, Z., Ortoleva, P., and Powley, D., 1994a, Three new exploration and development concepts for compartmented basins: January-April 1994 Quarterly Report to the Gas Research Institute, 82 p.

Al-Shaieb, Z., Puckette, J., Abdalla, A., and Ely, P., 1994b, Mega-compartment complex in the Anadarko Basin: a completely sealed overpressured phenomenon, *in* Ortoleva, P. (ed.), Basin compartments and seals: American Association of Petroleum Geologists Memoir 61, p. 55-68.

Al-Shaieb, Z., Puckette, J., Abdalla, A., and Rice, A., 1993c, Fault-associated reservoir compartments and seals in the Anadarko Basin: their relationship to basin evolution: October 1992-January 1993 Quarterly Report to the Gas Research Institute, p. 3-37.

Al-Shaieb, Z., Puckette, J., Abdalla, A., and Rice, A., 1994c, Porosity evolution in the upper Morrowan chert conglomerate reservoirs: Gas Research Institute Annual Report, p. 3-32.

Al-Shaieb, Z., Puckette, J., Abdalla, A., Tigert, V., and Ortoleva, P., 1994d, The banded character of pressure seals, *in* Ortoleva, P. (ed.), Basin compartments and seals: American Association of Petroleum Geologists Memoir 61, p. 351-367.

Al-Shaieb, Z., Puckette, J., Ely, P., and Abdalla, A., 1993d, Three levels of compartmentation within the overpressured interval of the Anadarko Basin, *in* Ortoleva, P. (ed.), Basin compartments and seals: American Association of Petroleum Geologists Memoir 61, p. 69-83.

Al-Shaieb, Z., Puckette, J., Ely, P., and Tigert, V., 1992b, Pressure compartments and seals in the Anadarko Basin: Oklahoma Geological Survey Circular 93, p. 210-228.

Al-Shaieb, Z., Puckette, J., Ely, P., and Abdalla, A., 1993e, The upper Morrowan fan-delta chert conglomerate in Cheyenne and Reydon Fields: completely sealed gas-bearing pressure compartments: Oklahoma Geological Survey Circular, v. 95, p. 26-39.

Al-Shaieb, Z. and Shelton, J. W., 1981, Migration of hydrocarbons and secondary porosity in sandstones: American Association of Petroleum Geologists Bulletin, v. 65, p. 2433-2436.

Amsden, T. W., 1957, Stratigraphy of the Hunton Group: Oklahoma Geological Survey Circular 44, 49 p.

Amsden, T. W., 1960, Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region; Part 6, Hunton stratigraphy: Oklahoma Geological Survey Bulletin 84, 311 p.

Amsden, T. W., 1975, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko basin of Oklahoma: Oklahoma Geological Survey Bulletin 121, 214 p.

Amsden, T. W., 1988, Depositional and post-depositional history of middle Paleozoic (Late Ordovician through Early Devonian) strata in the ancestral Anadarko basin, *in* Johnson, K.S., (ed.), Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular 90, p. 143-146.

Barker, C., 1972, Aquathermal pressuring- role of temperature in development of abnormal-pressure zones: American Association of Petroleum Geologists Bulletin, v. 56, no. 11, p. 2433-2436.

Barker, C., 1979, Role of temperature and burial depth in development of subnormal and abnormal pressures in gas reservoirs (abstract): American Association of Petroleum Geologists Bulletin, v. 63, p. 414-415.

Barrick, J. E., Klapper, G., Gilbert, and Amsden, T. W., 1990, Late Ordovician-Early Devonian conodont succession in the Hunton Group, Arbuckle Mountains and Anadarko Basin, Oklahoma *in* Ritter, S. M., (ed.) Early to Middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma: Oklahoma Geological Survey Guidebook 27, p. 55-62.

Berg, R. R. and Habeck, M. F., 1982, Abnormal pressure in the Lower Vicksburg, McAllen Ranch field, south Texas: Transactions of the Gulf Coast Association of Geological Societies, v. 32, p. 247-253.

Bethke, C. M., Harrison, W. J., Upson, C., and Altaner, S. P., 1988, Supercomputer analysis of sedimentary basins: Science, v. 239, p. 261-267.

Borak, B. and Friedman, G. M., 1981, Textures of sandstones and carbonate rocks in the world's deepest wells (in excess of 30,000 ft. or 9.1 km) Anadarko Basin, Oklahoma: Sedimentary Geology, v. 29., p. 133-151.

Bradley, J. S., 1975, Abnormal formation pressure: American Association of Petroleum Geologists Bulletin, v. 59, p. 2068-2071.

Brown, L. F., 1979, Delatic sandstone facies of the mid-continent, *in* Hyne, N. J., (ed.), Pennsylvanian Sandstones of the Mid-Continent: Tulsa Geological Society Special Publication no. 1, p. 35-63.

Budnik, R. T., 1986, Left-lateral intraplate deformation along the Ancestral Rocky Mountains: implications for Late Paleozoic plate reconstructions: tectonophysics, v. 132, p. 195-214.

Burst, J. F., 1969, Diagenesis of Gulf Coast clayey sediments and its possible relation to petroleum migration: American Association of Petroleum Geologists Bulletin, v. 53, p. 73-93.

Burke, K. and Dewey, J. F., 1973, Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks: Journal of Geology, v. 81, p. 406-433.

Cannon, G. E. and Craze, R. C., 1938, Excessive pressure and pressure variations with depth of petroleum reservoirs in the Gulf Coast region of Texas and Louisiana: Transactions of the American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 127, p. 31-38.

Chapman, R. E., 1972, Clays with abnormal interstitial fluid pressures: American Association of Petroleum Geologists Bulletin, v. 56, no. 4, p. 790-795.

Chapman, R. E., 1980, Mechanical versus thermal cause of abnormally high pore pressures in shales: American Association of Petroleum Geologists Bulletin, v. 64, p. 2179-2183.

Chase, G. W., 1954, Geological note on the Permian conglomerate around the Wichita Mountains, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 38, p. 2028-2035.

Chenoweth, P. A., 1979, Geological prospecting for Mid-Continent sandstones; *in* Hyne, N. J. (ed.), Pennsylvanian Sandstones of the Mid-Continent: Tulsa Geological Society Special Publication no. 1, p. 13-33.

Choquette, P. W., and Pray, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary rocks: American Association of Petroleum Geologists Bulletin, v. 54, no. 2, p. 207-250.

Craig, L. C., Connor, C. W., and others, 1979, Paleotectonic investigations of the Mississippian System in the United States: United States Geological Survey Professional Paper 1010, parts 1-3.

Dahlburg, E. C., 1995, Applied hydrodynamics in petroleum exploration: New York, Springer-Verlag, 295 p.

Daines, S. R., 1982, Aquathermal pressuring and geopressure evaluation: American Association of Petroleum Geologists Bulletin, v. 66, p. 931-939.

Davies, D. K. and Ethridge, F. G., 1975, Sandstone composition and depositional environment: American Association of Petroleum Geologists Bulletin, v. 59, p. 239-264.

Davis, G. H., 1984, Structural geology of rocks and regions: New York, John Wiley and Sons, 492 p.

Deming, D., 1994, Factors necessary to define a pressure seal: American Association of Petroleum Geologists Bulletin, v. 78, p. 1005-1009.

Denison, R. E., Hetherington, E. A., Jr., and Kenny, G. S., 1966, Isotopic-age dates from basement rocks on Oklahoma: Oklahoma Geology Notes, v. 26, p. 170-176.

Dickey, P. A., 1976, Abnormal formation pressure: Discussion: American Association of Petroleum Geologists Bulletin, v. 60, p. 1124-1128.

Dickinson, G., 1953, Geological aspects of abnormal reservoir pressures in Gulf Coast Louisiana: American Association of Petroleum Geologists Bulletin, v. 37, p. 410-432.

Dickinson, W. R., 1974, Plate tectonics and sedimentation, *in* Dickinson, W. R. (ed.), Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication no. 22, p. 1-27.

Donovan, R. N., Beauchamp, W., Ferraro, T., Lojek, C., McConnell, D., Munsil, M., Ragland, D., Sweet, B., and Taylor, D., 1983, Subsidence rates in Oklahoma during the Paleozoic: Oklahoma City Geological Society Shale Shaker Digest, v. 33, no. 8, p. 86-88.

Downey, M. W., 1984, Evaluating seals for hydrocarbon accumulations: American Association of Petroleum Geologists Bulletin, v. 68, no. 11, p. 1752-1763.

Dutton, S. P., 1982, Pennsylvanian fan-delta and carbonate deposition, Mobeetie field, Texas Panhandle: American Association of Petroleum Geologists Bulletin, v. 66, p. 389-407.

Engelder, J. T., 1974, Cataclasis and the generation of fault gouge: Geological Society of America Bulletin, v. 85, p. 1515-1522.

Evans, J. L., 1979, Major structural and stratigraphic features of the Anadarko Basin: *in* Hyne, N. J. (ed.), Pennsylvanian Sandstones of the Mid-Continent: Tulsa Geological Society Special Publication, no. 1, p. 97-113.

Feinstein, S., 1981, Subsidence and thermal history of the southern Oklahoma aulacogen: implications for petroleum exploration: American Association of Petroleum Geologists Bulletin, v. 65, no. 12, p. 2521-2533.

Fertl, W. H., 1976, Abnormal Formation Pressures: New York, Elsevier, 382 p.

Fraser, G. S. and Suttner, L., 1986, Alluvial fans and fan deltas: a guide to exploration for oil and gas: Boston, IHRDC, 199 p.

Freed, R. L. and Peacor, D. R., 1989, Geopressured shale and sealing effect of smectite to illite transition: American Association of Petroleum Geologists Bulletin, v. 73, p. 1223-1232.

Frezon , S. E. and Jordon, L., 1979, Texas Panhandle and Oklahoma, *in* Craig, L. C., Connor, C. W., and others (eds.), Introduction and regional analyses of the Mississippian System, part 1 *of* Paleotectonic investigations of the Mississippian System in the United States: United States Geological Survey Professional Paper 1010-I, p. 147-159.

Garner, D. L., and Turcotte, D. L., 1984, The thermal and mechanical evolution of the Anadarko Basin: Tectonophysics, v. 107, p. 1-24.

Goldstein, A. G., 1981, Comment on "plate tectonics of the Ancestral Rocky Mountains": Geology, v. 9, p. 387-388.

Gretener, P. E., 1990, Geomechanics in production geology and geophysics: Short Course Notes, Rocky Mountain Association of Geologists, Denver, 97 p.

Ham, W. E., 1969, Regional geology of the Arbuckle Mountains, Oklahoma: Oklahoma Geological Survey Special Publication 73-3, 61 p.

Ham, W. E., Denison, R. E., and Merritt, C. A., 1964, Basement rocks and structural evolution of southern Oklahoma: Oklahoma Geological Survey Bulletin 95, 302 p.

Ham, W. E. and Wilson, J. L., 1967, Paleozoic epierogeny and orogeny in the central United States: American Journal of Science, v. 265, p. 332-407.

Hansen, C. A., 1978, Subsurface Virgilian and Lower Permian arkosic facies, Wichita Uplift-Anadarko Basin, Oklahoma: unpublished M. S. thesis, Oklahoma State University, 63 p.

Hanson, R. E. and Al-Shaieb, Z., 1980, Voluminous subalkaline silicic magmas related to intracontinental rifting in the southern Oklahoma aulacogen: Geology, v. 8, p. 180-184.

Harlton, B. H., 1951, Faults in sedimentary part of Wichita Mountains of Oklahoma: American Association of Petroleum Geologists Bulletin, v. 35, no. 5, p. 988-999.

Harlton, B. H., 1963, Frontal Wichita fault system of southwestern Oklahoma: American Association of Petroleum Geologists Bulletin, v. 47, no. 8, p. 1552-1580.

Harlton, B. H., 1972, Faulted fold belts of southern Anadarko Basin adjacent to frontal Wichitas: American Association of Petroleum Geologists Bulletin, p. 1544-1551.

Hoffman, M. G., 1930, Geology and petrology of the Wichita Mountains: Oklahoma. Geological Survey Bulletin 52, 83 p.

Hoffman, P., Burke, K., and Dewey, J. F., 1974, Aulacogens and their genetic relation to geosynclines, with a Proterozoic example from Great Slave Lake, Canada, *in* Dott, R. H., Jr., and Shaver, R. H. (eds.), Modern and Ancient Geosyncline Sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 19, p. 38-55.

Hoffman, P., 1973, Evolution of an early Proterozoic continental margin: the Coronation geosyncline and associated geosynclines of the northwestern Canadian shield: Philosophical Transactions of the Royal Society of London Series A, v. 273, p. 547-581.

Houseknecht, D. W., 1988, Intergranular pressure solution in four quartzose sandstones: Journal of Sedimentary Petrology, v. 58, no. 2, p. 228-246.

Houseknecht, D. W., 1984, Influence of grain size and temperature on intergranular pressure solution, quartz cementation, and porosity in a quartzose sandstone: Journal of Sedimentary Petrology, v. 54, p. 348-361.

Houseknecht, D. W. and Hathon, L. A., 1987, Petrographic constraints on models of intergranular pressure solution in quartzose sandstones: Applied Geochemistry, v. 2,p. 507-521.

Hubbert, M. K. and Rubey, W. W., 1959, Role of fluid pressure in mechanics of overthrust faulting, I: Geological Society of America Bulletin, v. 70, p. 115-166.

Hunt, J. M., 1990, Generation and migration of petroleum from abnormally pressured fluid compartments: American Association of Petroleum Geologists Bulletin, v. 74, no. 1, p. 1-12.

Johnson, K. S., 1989, Geologic evolution of the Anadarko Basin, *in* Johnson, K. (ed.), Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, p. 3-12.

Johnson, K. S., 1991, Geologic overview and economic importance of Late Cambrian and Ordovician rocks in Oklahoma, *in* Johnson, K. S. (ed.), Late Cambrian-Ordovician geology of the southern mid-continent, 1989 symposium: Oklahoma Geological Survey Circular 92, p. 3-14.

Johnson, K. S. and Cardott, B. J., 1992, Geologic framework and hydrocarbon source rocks of Oklahoma, *in* Johnson, K. S. and Cardott, B. J., (eds.), Source rocks in the southern Mid-Continent, 1990 Symposium: Oklahoma Geological Survey Circular 93, p. 21-37.

Johnson, K. S., Denison, R. E., Dutton, S. P., Goldstein, A. G., Rascoe, B., Sutherland, P. K., and Thompson, D. M., 1988, Southern mid-continent region, *in* The Geology of North America, v. D-2, Sedimentary Cover-North American Craton United States: Geological Society of America.

Kluth, C. F. and Coney, P. J., 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, p. 10-15.

Leder, F., and Park, W. C., 1986, Porosity reduction in sandstone by quartz overgrowth: American Association of Petroleum Geologists Bulletin, v. 70, no. 11, p. 1713-1728.

Lemiszki, P. J. and Brown, L. D., 1988, Variable crustal structure of strike-slip fault zones as observed on deep seismic reflection profiles: Geological Society of America Bulletin, v. 100, p. 665-676.

Luo, M., Baker, M. R., and LeMone, D. V., 1994, Distribution and generation of the overpressure system, eastern Delaware Basin, western Texas and southern New Mexico: American Association of Petroleum Geologists Bulletin, v. 78, no. 9, p. 1386-1405.

Luza, K. V., 1989, Neotectonics and seismicity of the Anadarko Basin, *in* Johnson, K. (ed.), Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, p. 121-132.

Lyday, J. R., 1985, Atokan (Pennsylvanian) Berlin Field: Genesis of recycled detrital dolomite reservoirs, deep Anadarko Basin, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 69, p. 1931-1949.

Magara, K., 1975, Importance of aquathermal pressuring effect in Gulf Coast: American Association of Petroleum Geologists Bulletin, v. 59, p. 2037-2045.

Manni, F. M., 1985, Depositional environment, diagenesis, and unconformity identification of the Chimneyhill Subgroup in the western Anadarko Basin and northern shelf, Oklahoma: Oklahoma State University unpublished M.S. thesis, 133 p.

Martinsen, R. S., 1994, Summary of published literature on anomalous pressures: Implications for the study of pressure compartments: *in* Ortoleva, P. (ed.), Basin compartments and seals: American Association of Petroleum Geologists Memoir 61, p. 27-38.

McConnell, D. A., 1987, Paleozoic structural evolution of the Wichita Uplift, southwestern Oklahoma: unpublished Ph.D. dissertation, Texas A&M University, 221 p.

McConnell, D. A., 1989, Constraints on the magnitude and sense of slip across the northern margin of the Wichita Uplift, southwest Oklahoma, *in* Johnson, K. (ed.), Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, p. 85-96.

McConnell, D. A., Goydas, M. J., Smith, G. N., and Chitwood, J. P., 1990, Morphology of the frontal fault zone, southwest Oklahoma: implications for deformation and deposition in the Wichita Uplift and Anadarko Basin: Geology, v. 18, p. 634-637.

Medlock, P. L., 1984, Depositional environment and diagenetic history of the Frisco and Henryhouse Formations in central Oklahoma: unpublished M.S. thesis, Oklahoma State University, 146 p.

Meuhlberger, W. R. and others, 1966, Geochronology of the Mid-Continent region, United States: Journal of Geophysical Research, v. 71, p. 5409-5425.

Miller, J. A., 1981, Uranium potential of Lower Permian arkosic facies, northern Kiowa County, Oklahoma: unpublished M.S. thesis, Oklahoma State University, 65 p.

Moody, J. D. and Hill, M. J., 1956, Wrench fault tectonics: Geological Society of America Bulletin, v. 67, p. 1207-1246.

Moore, G. E., 1979, Pennsylvanian paleogeography of the southern mid-continent, *in* Hyne, N. J. (ed.), Pennsylvanian Sandstones of the Mid-Continent: Tulsa Geological Society Special Publication., no.1, p. 2-12.

O'Brien, J. J., and Lerche, I., 1986, The preservation of primary porosity through hydrocarbon entrapment during burial: Formation Evaluation, v. 1, no. 3, p. 295-299.

Ortoleva, P., Al-Shaieb, Z., and Puckette, J., 1995, Genesis and dynamics of basin compartments and seals: American Journal of Science, vol. 295, p. 345-427.

Osborne, M. J. and Swarbrick, R. E., 1997, Mechanisms for generating overpressure in sedimentary basins: a reevaluation: American Association of Petroleum Geologists Bulletin, v. 81, p. 1023-1041.

Perry, W. J., 1989, Tectonic evolution of the Anadarko Basin region, Oklahoma: United States Geological Society Bulletin 1886-A, 19 p.

Pickering, L. A. and Indelicata, G. J., 1985, Abnormal formation pressure; a review: The Mountain Geologist, v. 22, p. 78-89.

Pittman, E. D.,1981, Effect of fault-related granulation on porosity and permeability of quartz sandstones, Simpson Group (Ordovician), Oklahoma: American Association of Petroleum Geologists Bulletin, v. 65, no. 11, p. 2381-2387.

Pittman, E. D., 1972, Diagenesis of quartz in sandstones as revealed by scanning electron microscopy: Journal of Sedimentary Petrology, v. 42, p. 507-519.

Pittman, E. D. and Lumsden, D. N., 1968, Relationship between chlorite coatings on quartz grains and porosity, Spiro Sand, Oklahoma: Journal of Sedimentary Petrology, v. 38, no. 2, p. 668-670.

Plumley, W. J., 1980, Abnormally high fluid pressure: survey of some basic principles: American Association of Petroleum Geologists Bulletin, v. 64, p. 414-430.

Powers, M. C., 1967, Fluid release mechanisms in compacting marine mudrocks and their importance in oil exploration: American Association of Petroleum Geologists Bulletin, v. 51, no. 7, p. 1240-1254.

Powley, D. E., 1987, Subsurface fluid compartments: Gas Research Institute Gas Sands Workshop, Chicago, 1987.

Powley, D. E., 1989, Pressures and hydrogeology in petroleum basins: Spring 1989 Lectures in Egypt, 23 p.

Rascoe, B. A., and Adler, F. J., 1983, Permo-Carboniferous hydrocarbon accumulations, Mid-Continent, United States of America: American Association of Petroleum Geologists Bulletin, v. 67, p. 979-1001.

Rascoe, B. A., 1962, Regional stratigraphic analysis of Pennsylvanian and Permian rocks in western Mid-Continent, Colorado, Kansas, Oklahoma, Texas: American Association of Petroleum Geologists Bulletin, v. 46, no. 8, p. 1345-1370.

Rich, J. L., 1951, Three critical environments of deposition and criteria for recognition of rocks deposited in each of them: Geological Society of America Bulletin, v. 62, p. 1-20.

Rice, D. D., Threlkeld, C. N., and Vuletich, A. K., 1988, Character, origin and natural occurrence of natural gases in the Anadarko Basin, southwestern Kansas, western Oklahoma and Texas Panhandle, United States of America: Chemical Geology, v. 71, p. 149-157.

Rubey, W. W. and Hubbert, M. K., 1959, Role of fluid pressure in mechanics of overthrust faulting, II: Geological Society of America Bulletin, v. 70, p. 166-205.

Sahay, B. and Fertl, W. H., 1988, Origin and Evaluation of Formation Pressures: Boston, Kluwer, 292 p.

Schatski, N. S., 1946, The Great Donets Basin and Wichita system: comparative tectonics of ancient platforms: Akademiya Nauk S.S.S.R. Izvestiya Seriya Geologicheskaya, no. 1, p. 5-62.

Seale, J. D., 1981, Depositional Environments and diagenesis of upper flanks of the Anadarko Basin: Oklahoma City Geological Society Shale Shaker Digest, v. 32, p. 1.

Shannon, J. P., Jr., 1962, Hunton Group (Silurian-Devonian) and related strata in Oklahoma: American Association of Petroleum Geologists Bulletin, v. 46, p. 1-29.

Shelby, J. M., 1980, Geologic and economic significance of the upper Morrow chert conglomerate reservoir of the Anadarko Basin: Journal of Petroleum Technology, v. 32, no. 3, p. 489-495.

Shelton, J. W., 1973, Models of sand and sandstone deposits: a methodology for determining sand genesis and trend: Oklahoma Geological Survey Bulletin 18.

Shepherd, L. D., Drzewiecki, P. A., Bahr, J. M., and Simo, J. A., 1994, Silica budget for a diagenetic seal: American Association of Petroleum Geologists Memoir 61, p. 369-384.

Sloss, L. L., 1988, Tectonic evolution of the craton in Phanerozoic time: *in* Sloss, L. L. (ed.), The Geology of North America, v. D-2, Sedimentary Cover-North American Craton, United States: Geological Society of America, p. 25-51.

Smith, D. A., 1966, Theoretical considerations of sealing and non-sealing faults: American Association of Petroleum Geologists Bulletin v. 50, no. 2, p. 363-374.

Smith, D. A., 1980, Sealing and nonsealing faults in Louisiana Gulf Coast Salt Basin: American Association of Petroleum Geologists Bulletin, v. 64, no. 2, p. 145-172.

Stuart, C. A., 1970, Geopressures: Shell Oil Company, 121 p.

Swesnik, R. M., 1950, Golden trend of south-central Oklahoma: American Association of Petroleum Geologists Bulletin, v. 34, no. 3., p. 386-422.

Tigert, V. A., 1989, Identification and characterization of a pressure seal in south-central Oklahoma: unpublished M.S. thesis, Oklahoma State University, 83 p.

Tigert, V. A., and Al-Shaieb, Z., 1990, Pressure seals: their diagenetic banding patterns: Earth Science Reviews, v. 29, p. 227-240.

Veile, G. W., 1986, The subduction of Texas: Geological Society of America Abstracts with Programs, v. 18, p. 779.

Walker, P. E., 1986, a regional study of the diagenetic and geochemical character of the Pennsylvanian Morrow formation, Anadarko Basin, Oklahoma: unpublished M.S. thesis, Oklahoma State University, 156 p.

Walker, R. G., 1978, Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps: American Association of Petroleum Geologists Bulletin, v. 62, no. 6, p. 932-966.

Walker, R. G., 1980, Modern and ancient submarine fans: models for exploration for stratigraphic traps exploration of turbidites and other deep water sandstones: American Association of Petroleum Geologists Bulletin, v. 64, no. 6, p. 1101-1108.

Walper, J. L., 1970, Wrench faulting in the Mid-Continent: Oklahoma City Geological Society Shale Shaker Digest, v. 21, p. 32-36.

Walper, J. L., 1977, Paleozoic tectonics of the southern margin of North America: Transactions of the Gulf Coast Association of Geological Societies, v. 27, p. 231-238.

Webster, R. E., 1980, Evolution of southern Oklahoma aulacogen: Oil and Gas Journal, v. 78, no. 7, p. 150-172.

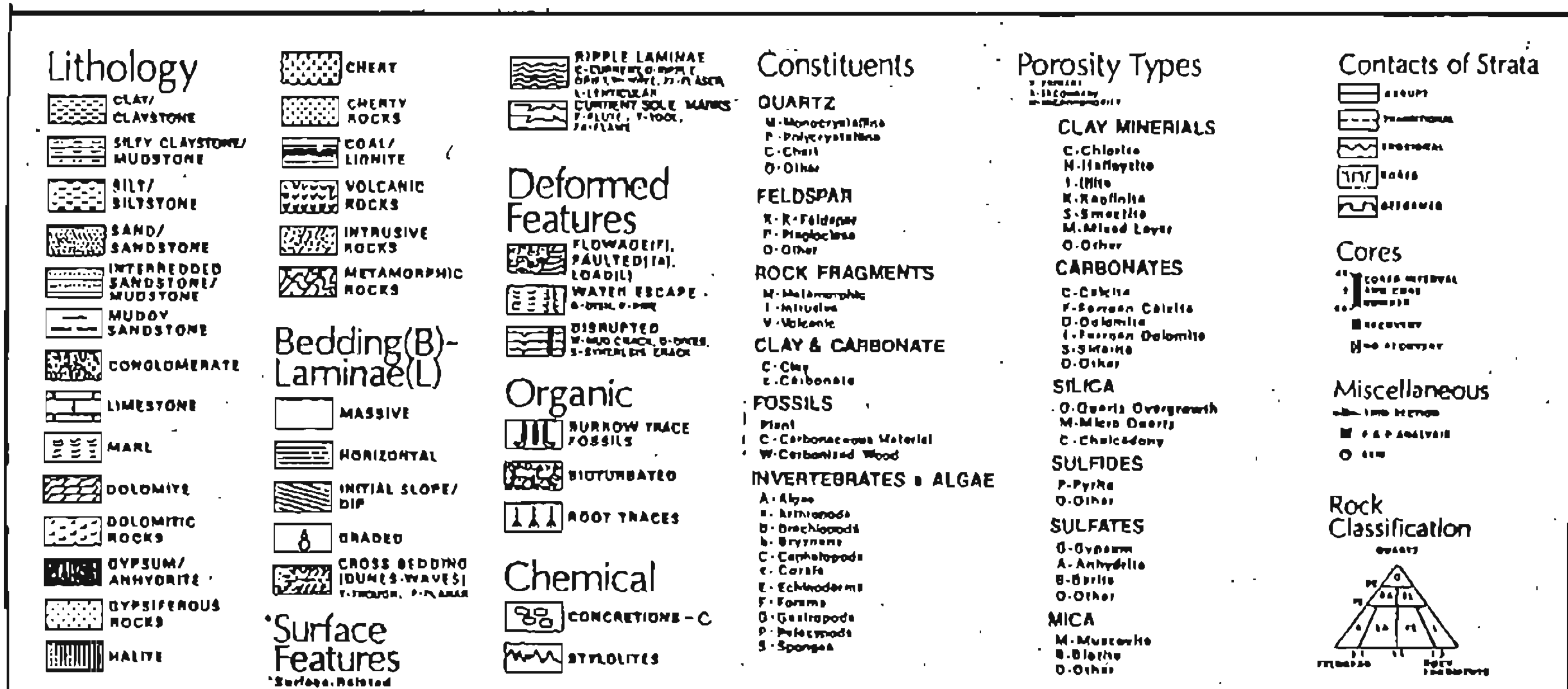
Wickham, J. W., 1978, The southern Oklahoma aulacogen, *in* Field guide to the structure and stratigraphy of the Ouachita Mountains and the Arkoma Basin: Annual meeting of American Association of Petroleum Geologists, Oklahoma City, 111 p.

Wilson, M. D. and Pittman, E. D., 1977, Authigenic clays in sandstones, recognition and influence on reservoir and paleoenvironmental analysis: Journal of Sedimentary Petrology, v. 47, no. 1, p. 3-31.

Yielding, G., Freeman, B., and Needham, D. T., 1997, Quantitative fault seal prediction: American Association of Petroleum Geologists Bulletin, v. 81, p. 897-917.

APPENDIX A

PETROLOGIG LOGS

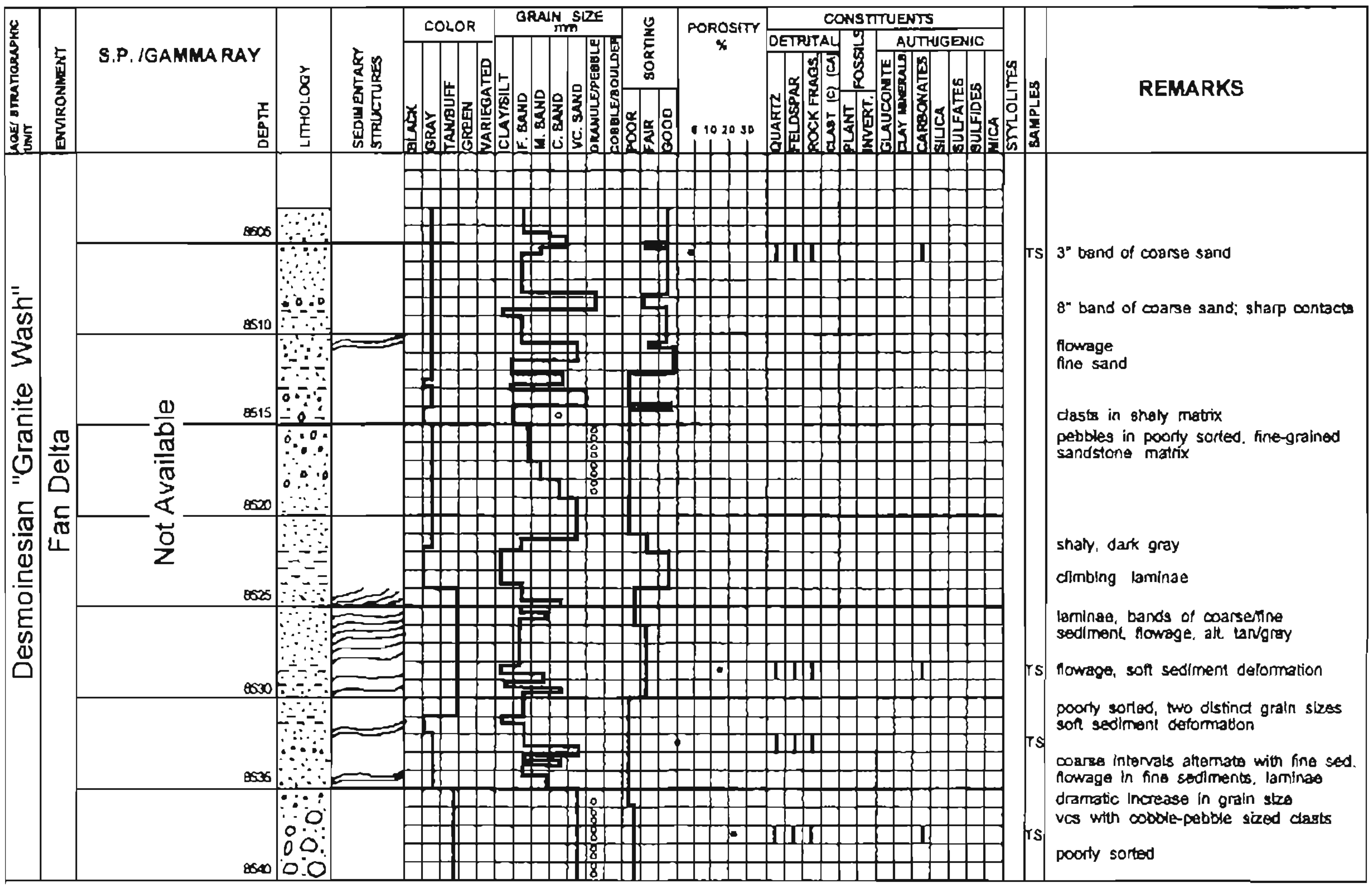


Lithology
CLAY/ CLAYSTONE
SILTY CLAYSTONE/ MUDSTONE
SILT/ SILTSTONE
SAND/ SANDSTONE
INTERBEDDED SANDSTONE/ MUDSTONE
MUDDY SANDSTONE
CONGLOMERATE
LIMESTONE
MARL
DOLOMITE
DOLOMITIC ROCKS
GYPSUM/ ANHYDRITE
GYPSIFEROUS ROCKS
HALITE
CHERT
CHERTY ROCKS
COAL/ LIGNITE
VOLCANIC ROCKS
INTRUSIVE ROCKS
METAMORPHIC ROCKS
Bedding(B)- Laminae(L)
MASSIVE
HORIZONTAL
INITIAL SLOPE/ DIP
GRADED
CROSS BEDDING (DUNES-WAVES)
*Surface Features
RIPPLE LAMINAE
CURRENT SOLE MARKS
Deformed Features
FLOWAGE(F), FAULTED(FA), LOAD(L)
WATER ESCAPE
DISRUPTED
Organic
BURROW TRACE FOSSILS
BIOTURBATED
ROOT TRACES
Chemical
CONCRETIONS - C
STYLOLITES
Constituents
QUARTZ
FELDSPAR
ROCK FRAGMENTS
CLAY & CARBONATE
FOSSILS
INVERTEBRATES & ALGAE
Porosity Types
CLAY MINERALS
CARBONATES
SILICA
SULFIDES
SULFATES
MICA
Contacts of Strata
Cores
Miscellaneous
Rock Classification

PETROLOGIC LOG

COMPANY/WELL NAME Shell Whitledge No. 1-8

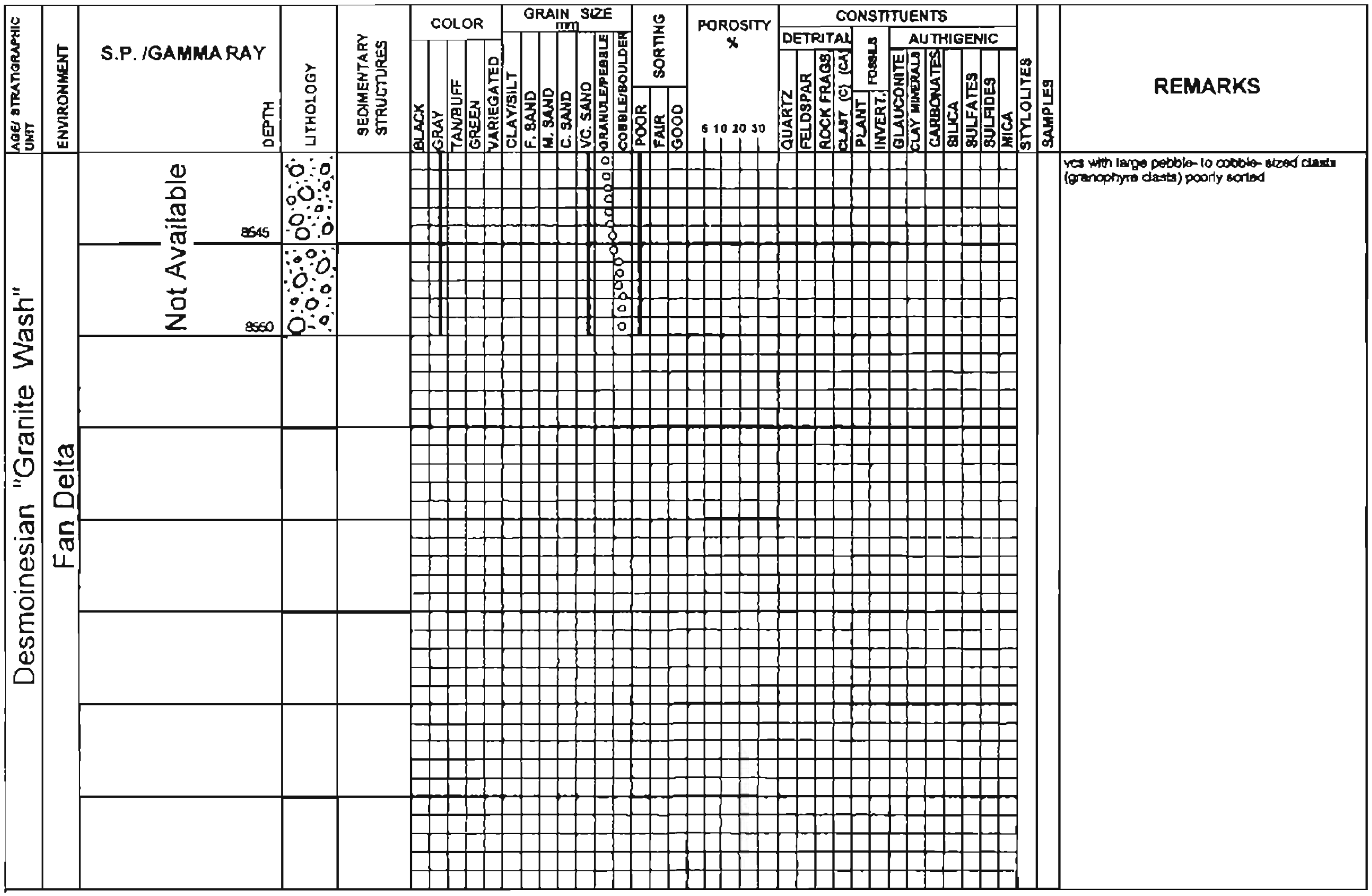
LOCATION Sec. 8, T.9N., R.22W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME Shell Whitledge No. 1-8

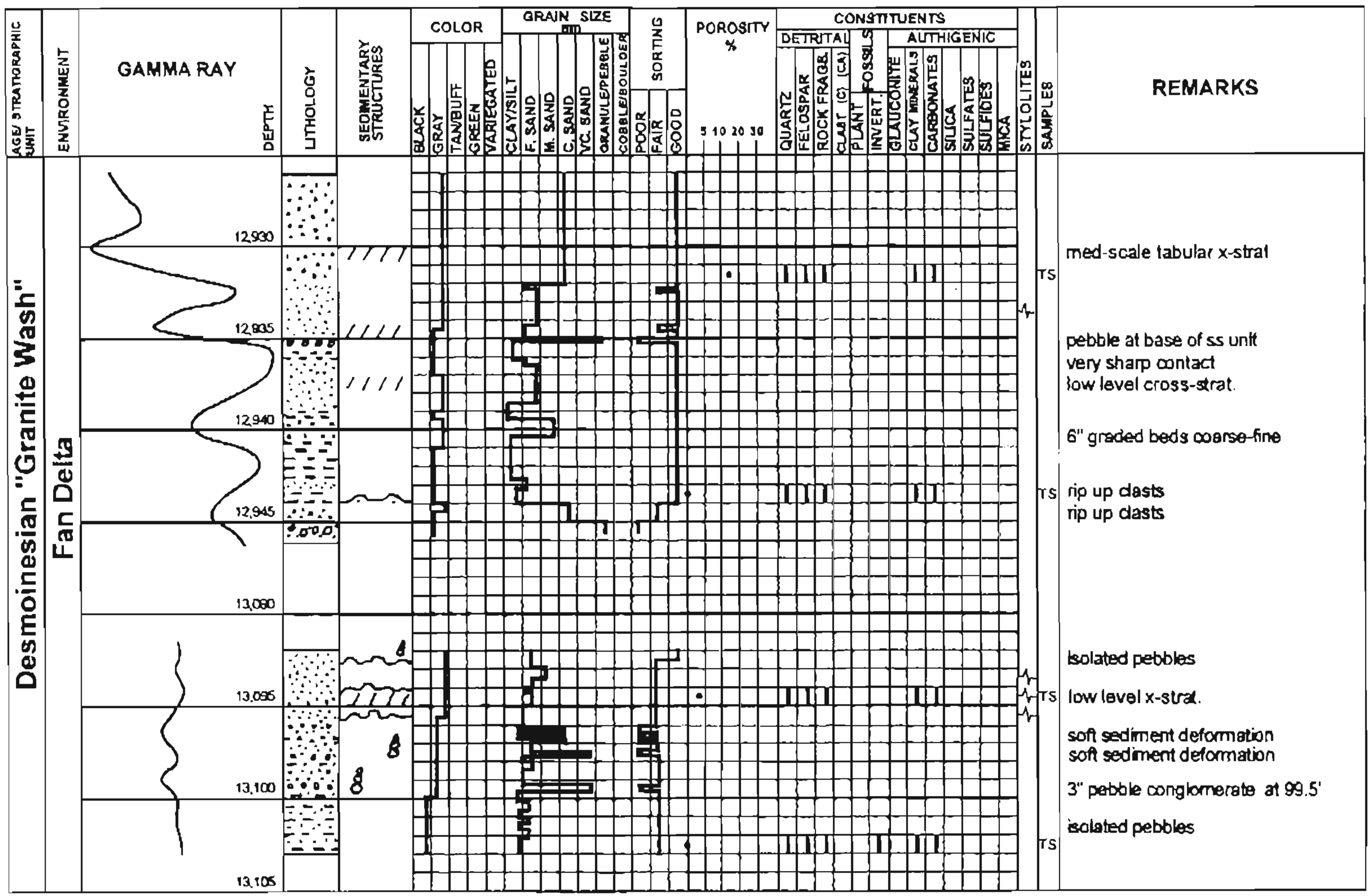
LOCATION Sec. 8, T.9.N., R.22W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME Exxon Felton No. 1-6

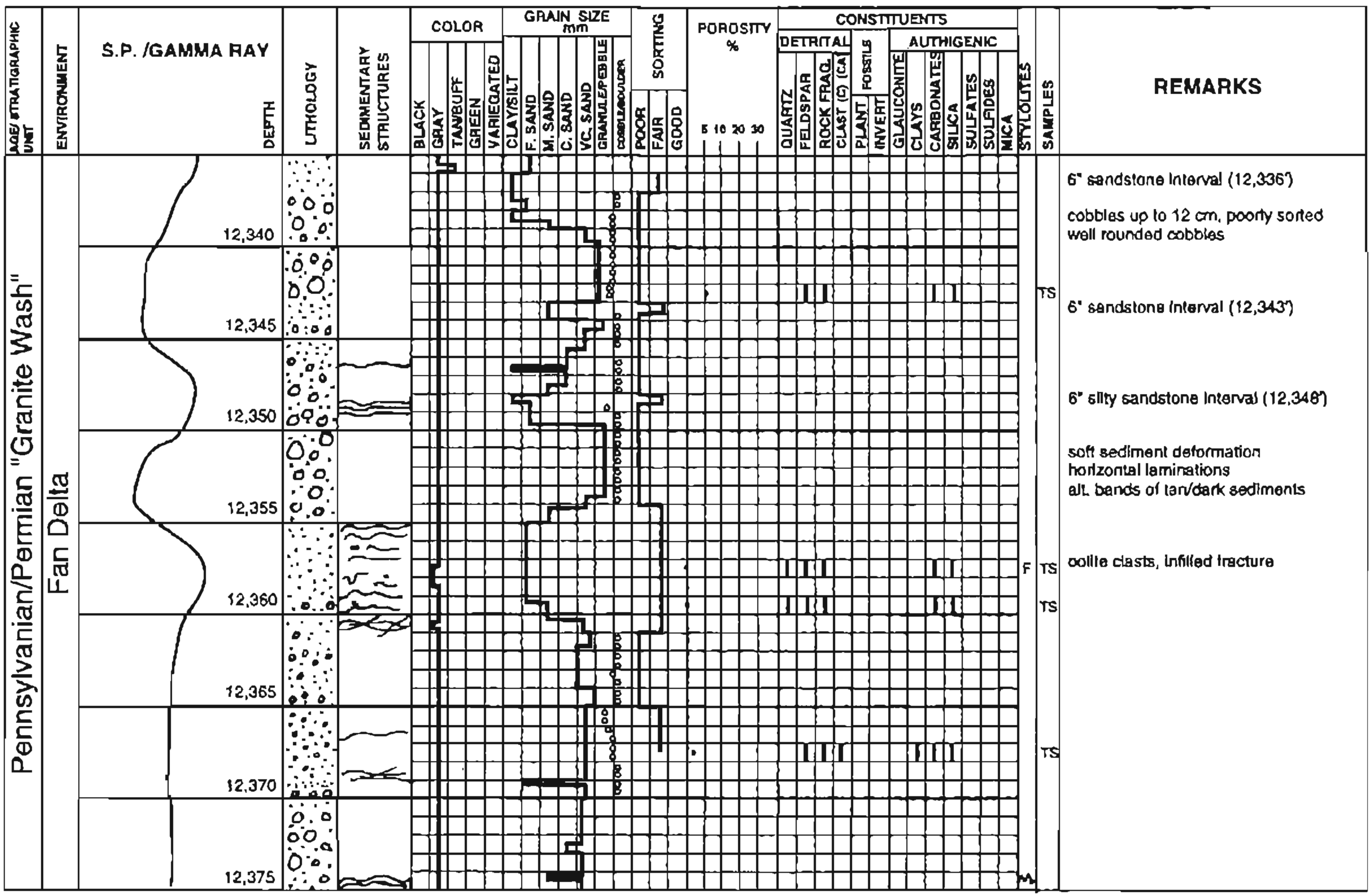
LOCATION Sec. 6, T.10N., R.22W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME Gulf Oil Co. Paine Community No. 1

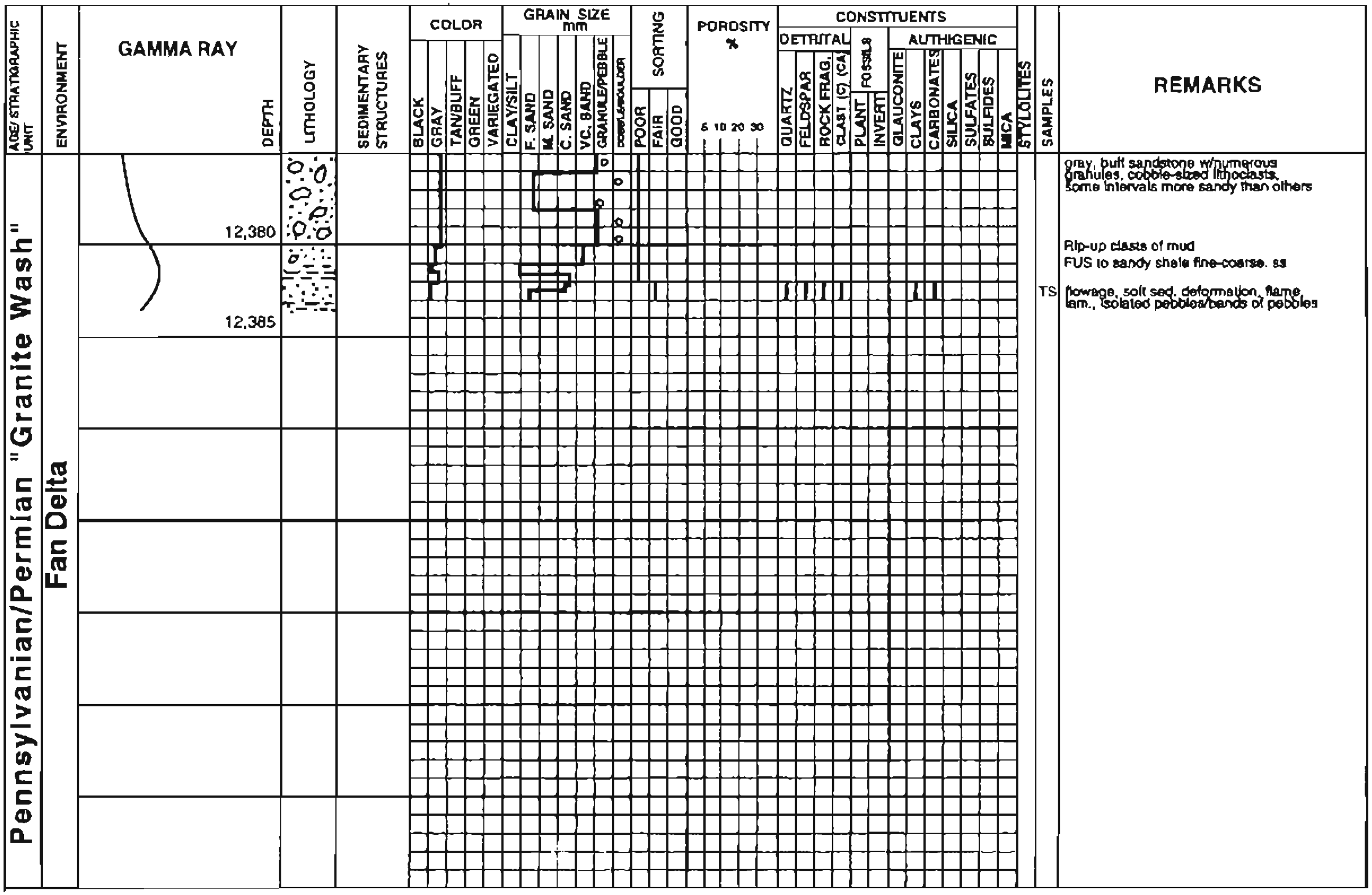
LOCATION Sec. 13, T.10N., R.26W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME Gulf Oil Co. Community Paine No. 1

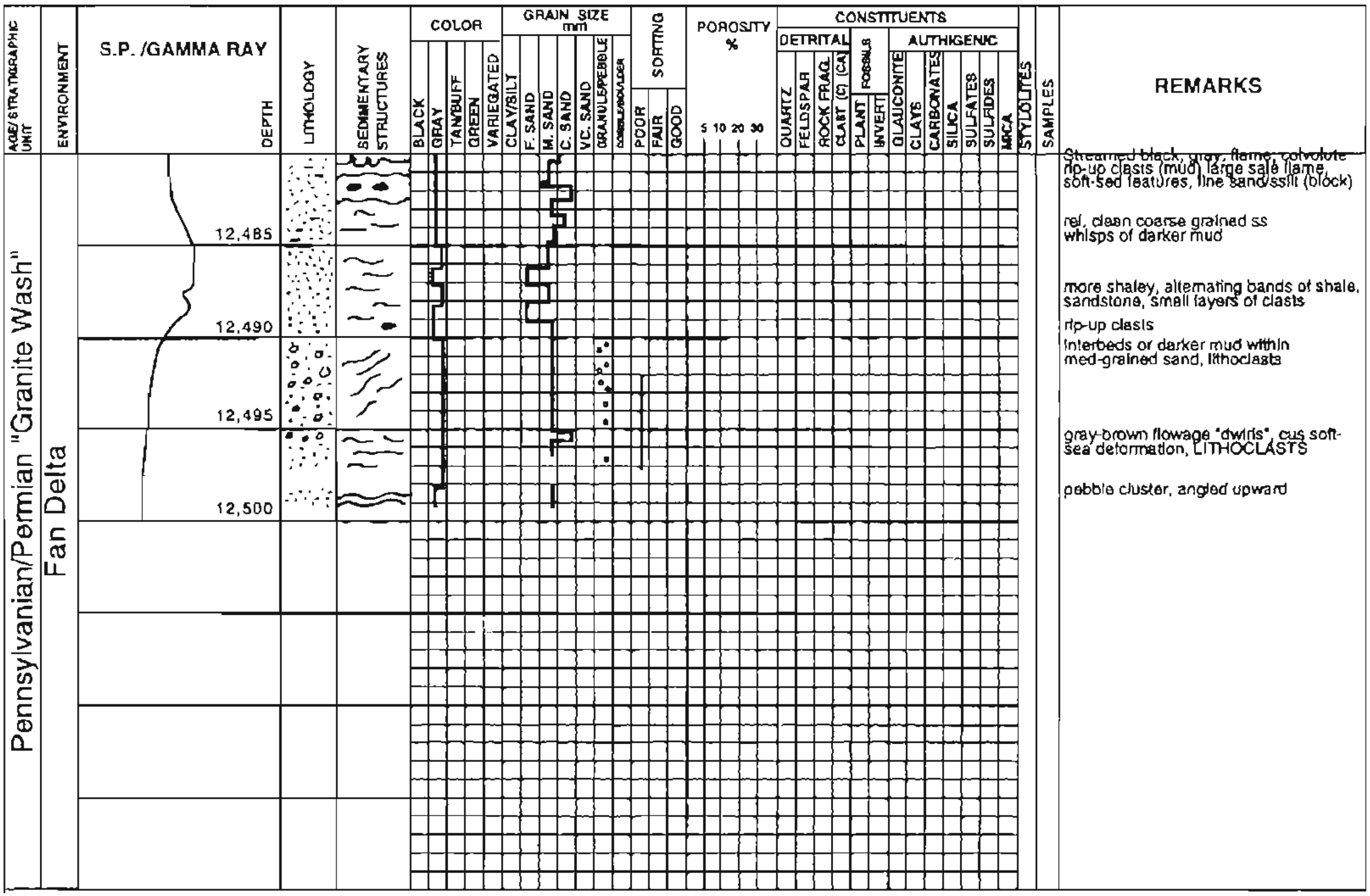
LOCATION Sec. 13, T.10N., R.26W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME Gulf Oil Co. Community Paine No. 1

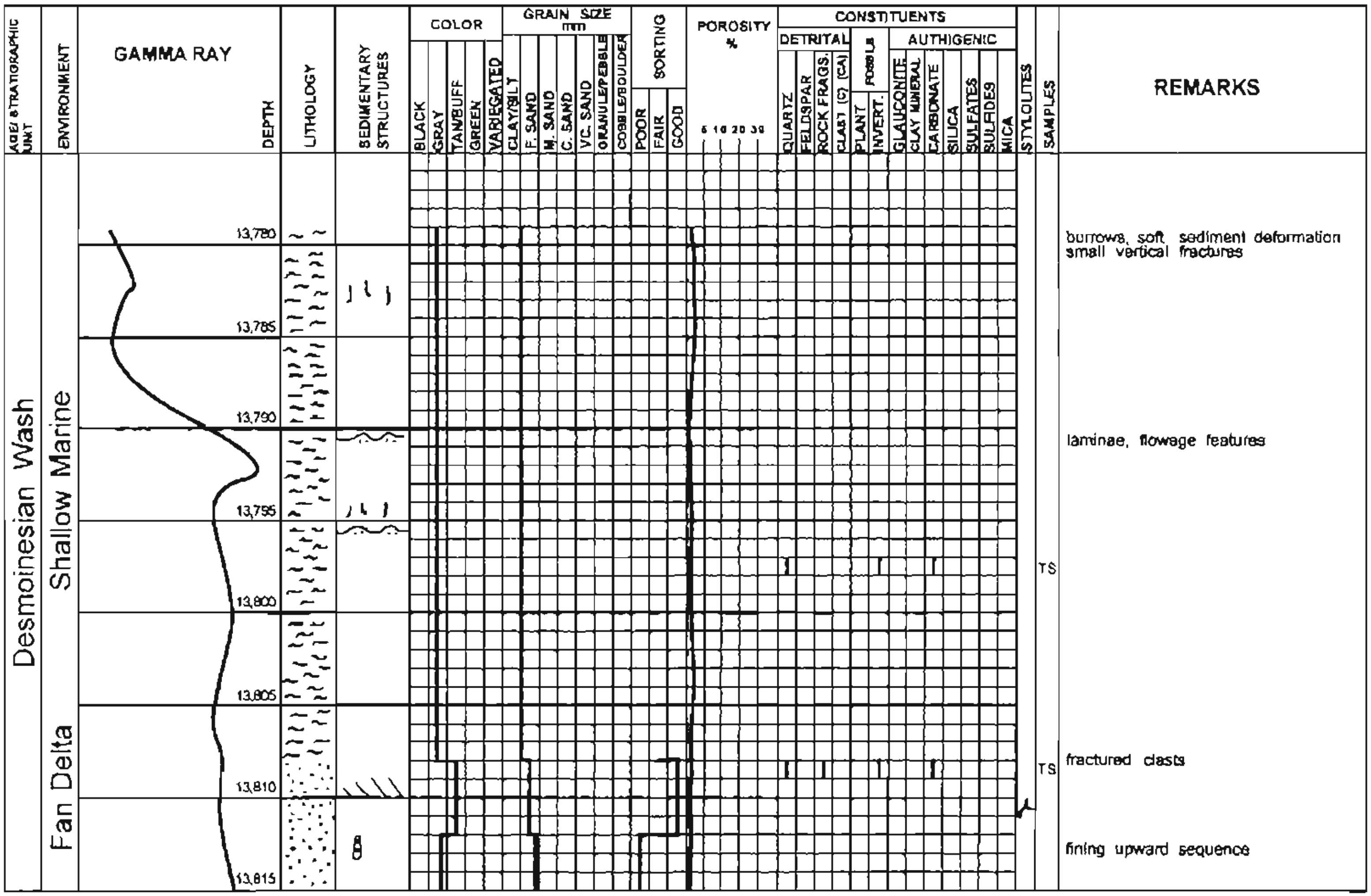
LOCATION Sec. 13, T.10N., R.26W. Beckham Co., OK



PETROLOGIC LOG

COMPANY/WELL NAME G.H.K. Kennemer No. 1-22

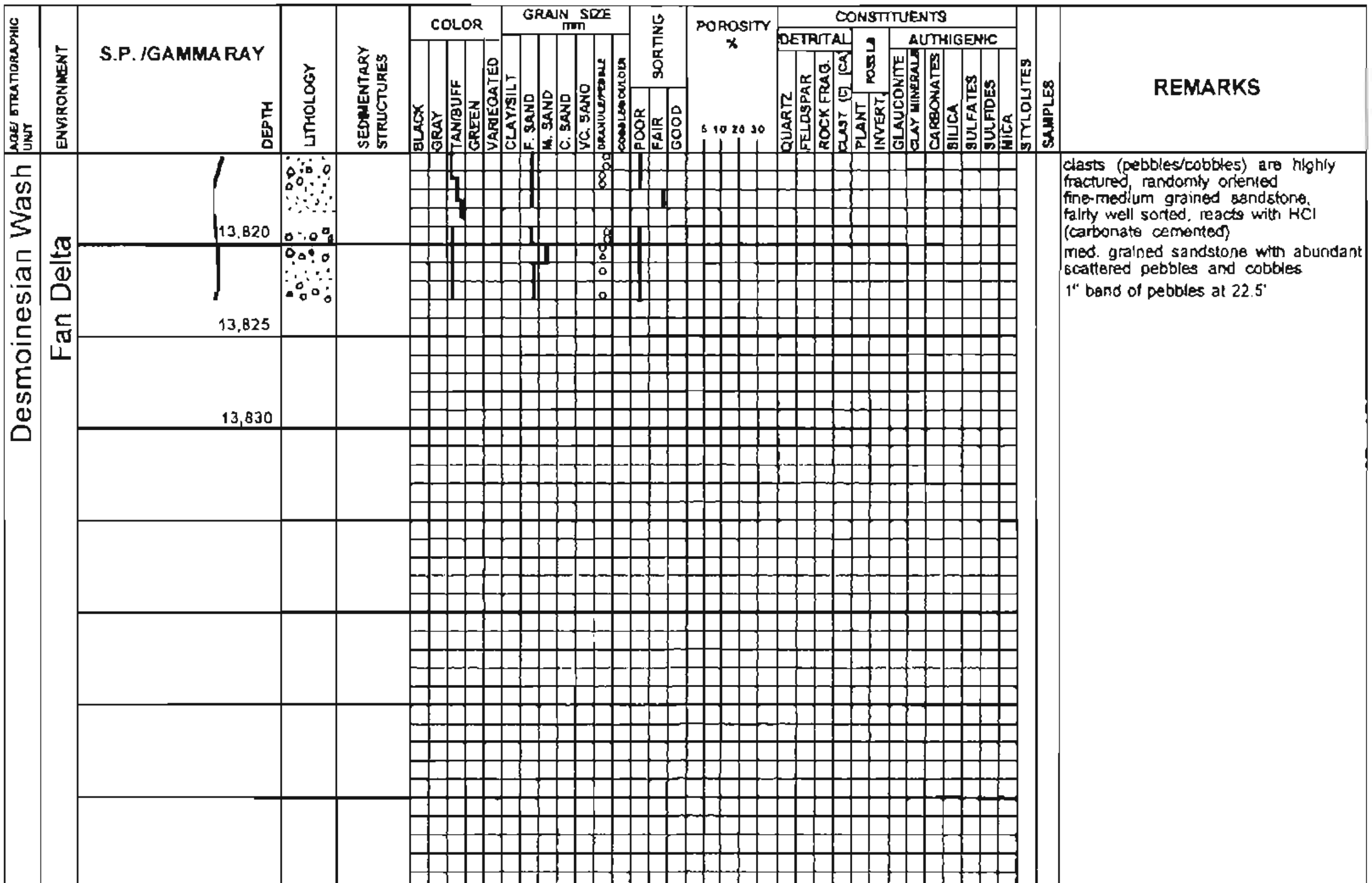
LOCATION Sec. 22, T.9N., R.21W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME G.H.K. Kennemer No. 1-22

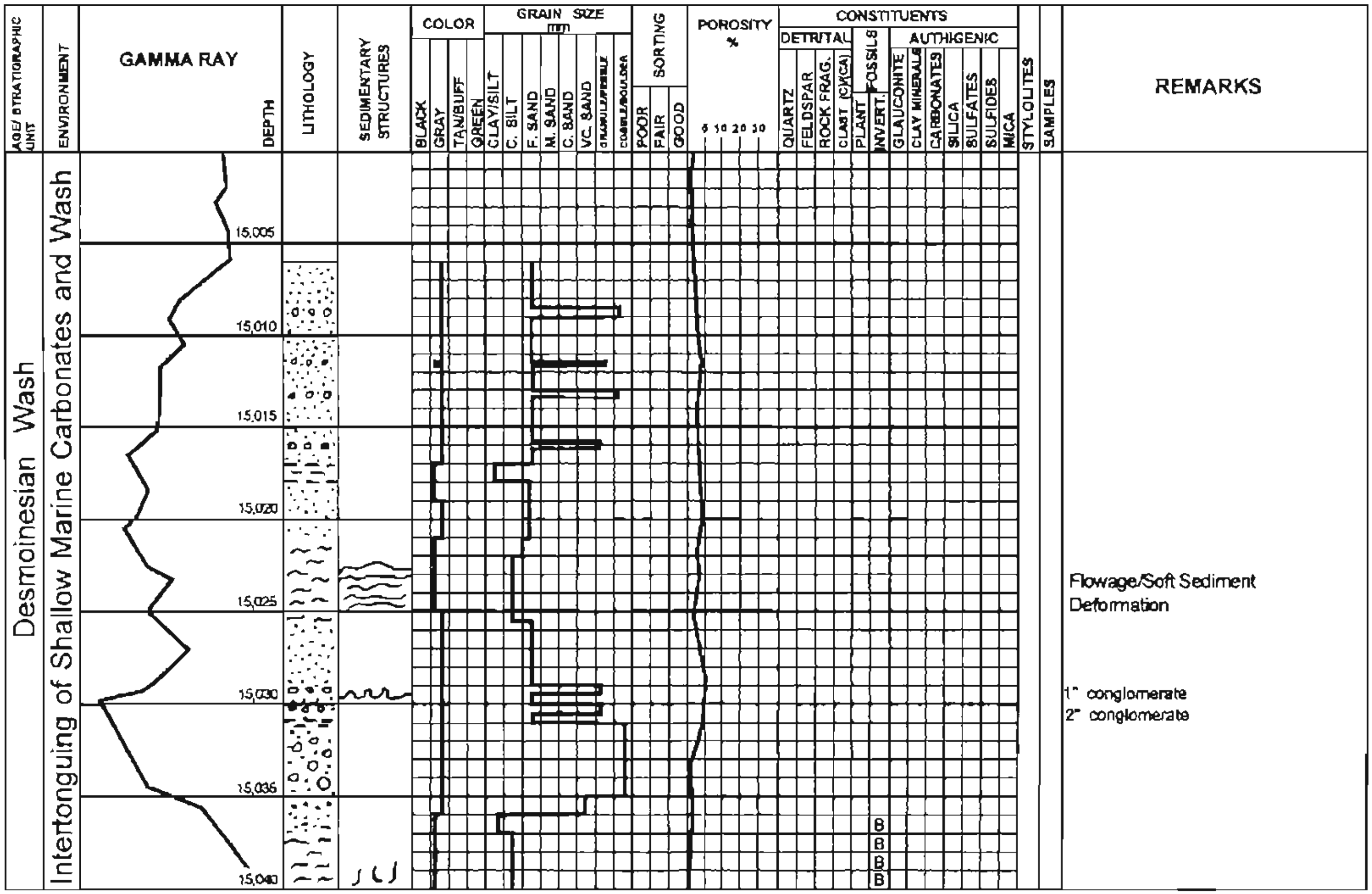
LOCATION Sec. 22, T.9N., R.21W. Beckham County, OK



PETROLOGIC LOG

COMPANY/WELL NAME GHK Kennemer No. 1-22

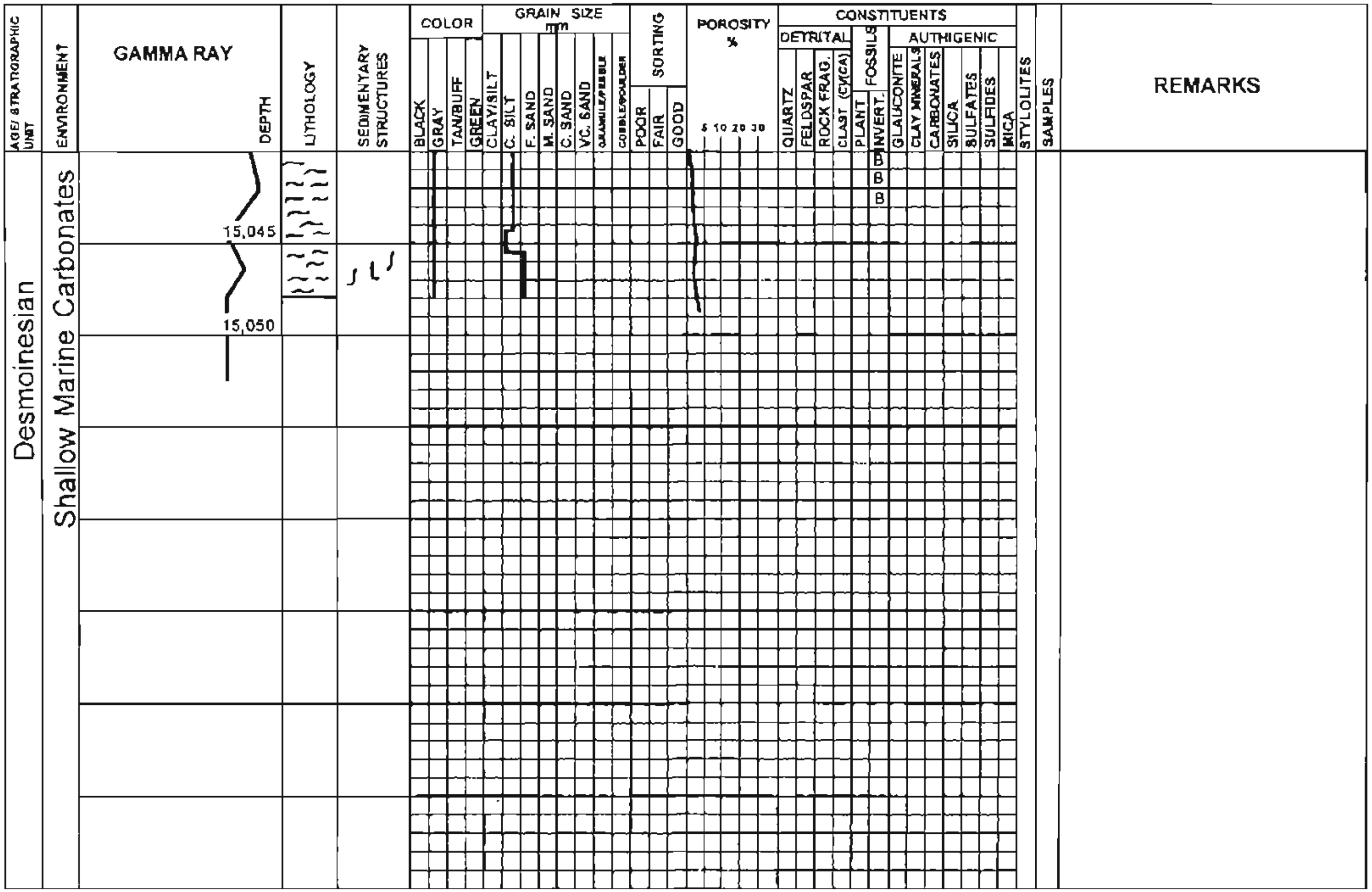
LOCATION Sec. 22, T.9N., R.21W. Beckham Co., OK



PETROLOGIC LOG

COMPANY/WELL NAME GHK Kennemer No. 1-22

LOCATION Sec. 22, T.9N., R.21W. Beckham Co., OK



LITHOLOGY

- SANDSTONE
- SHALE
- LIMESTONE
- DOLOMITIC LIMESTONE
- DOLOMITE
- CLAYEY DOLOMITE
- BRECCIA
- CRACKLE BRECCIA
- CHERT

SED. STRUCTURES/ CONSTITUENTS

- ALGAL LAMINATIONS
- TRILOBITES
- MOTTLED BEDDING
- STROMATOLITE
- INTRACLASTS
- GASTROPODS
- ALGAE
- VUGS, CHANNELS
- CEMENT VEIN
- CROSS-BEDDING
- G GLAUCONITE
- PYRITE
- CORALS
- BRACHIOPODS
- ECHINODERMS
- BURROWS
- OSTRACODS
- BRYOZOANS
- OOIDS
- UNCONFORMITY

POROSITY TYPES

F FRACTURE
SEF SOLUTION-ENLARGED FRACTURE
V VUGULAR
M MOLDIC
IG INTERGRANULAR
IX INTERCRYSTALLINE

CLAST SHAPE

A ANGULAR
SA SUBANGULAR
SR SUBROUNDED
R ROUNDED

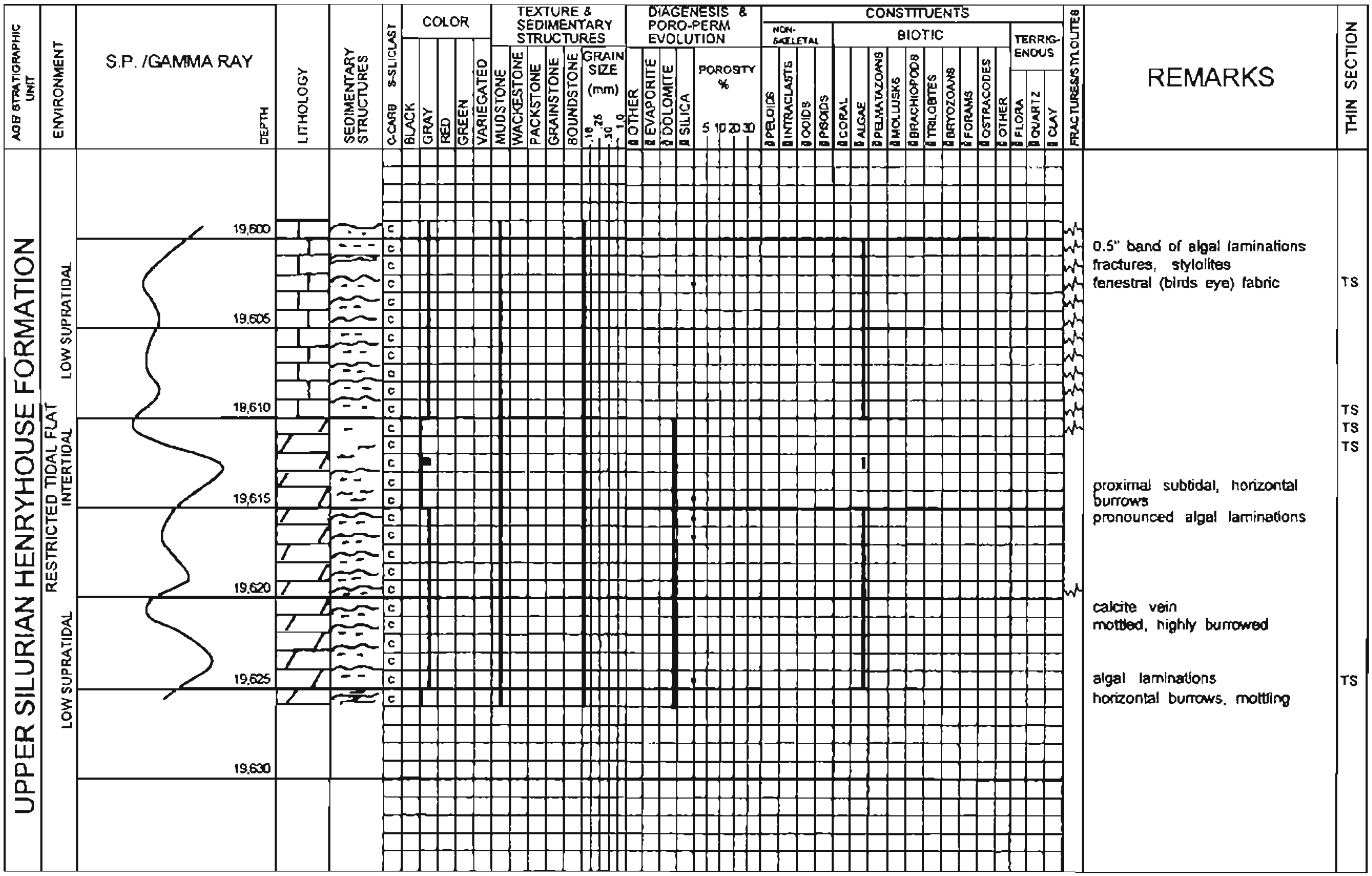
MISCELLANEOUS

DOMINANT FEATURE, TEXTURE
LESS COMMONLY OCCURRING
cmt. CEMENT
MISSING CORE
r RARE c COMMON
a ABUNDANT
THIN SECTION

PETROLOGIC LOG

COMPANY/WELL NAME Apexco (Natomas) Green No. 1

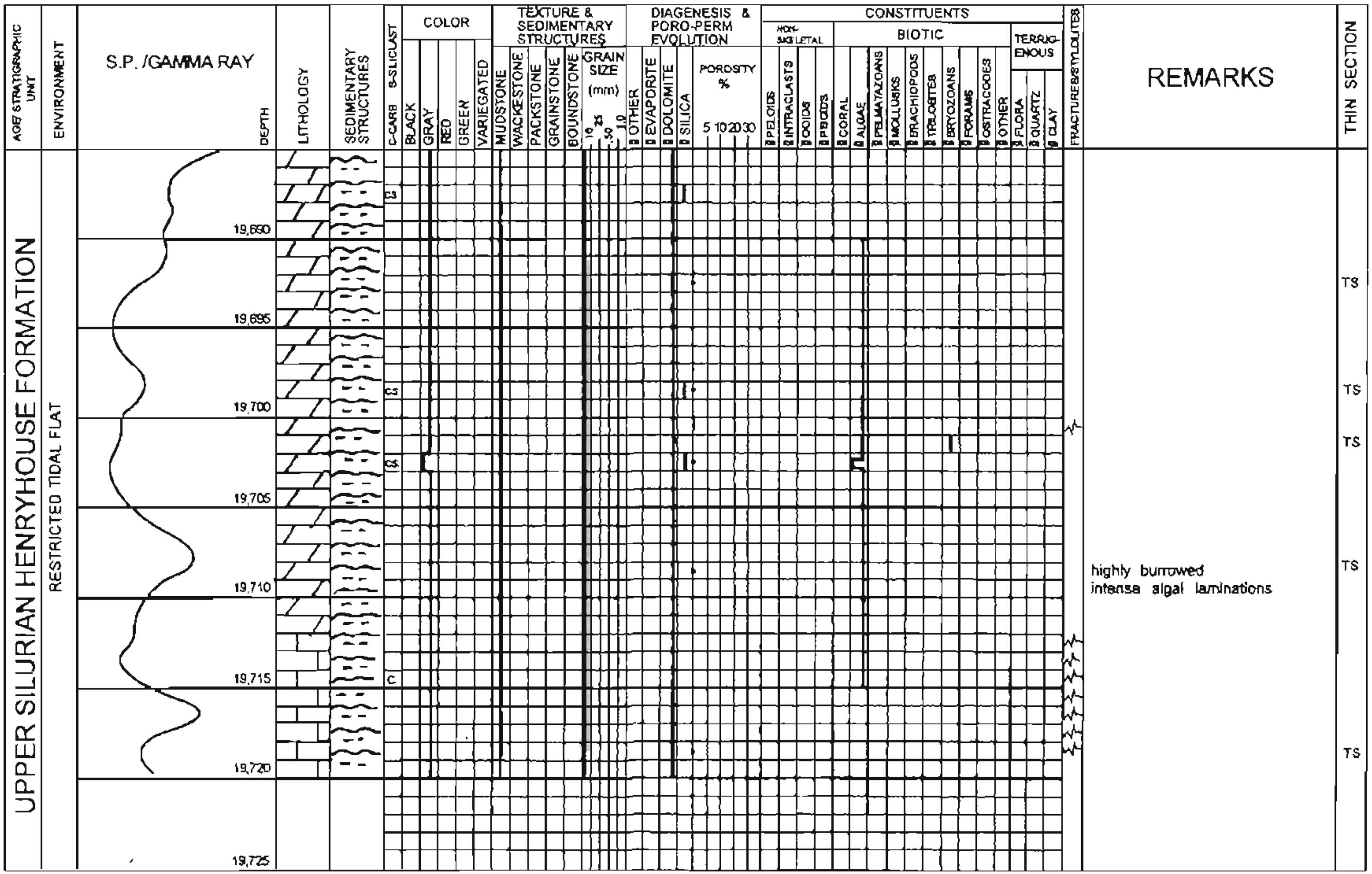
LOCATION Sec. 31, T.10N., R.26W. Beckham County, Oklahoma



COMPANY/WELL NAME Apexco (Natomas) Green No. 1

PETROLOGIC LOG

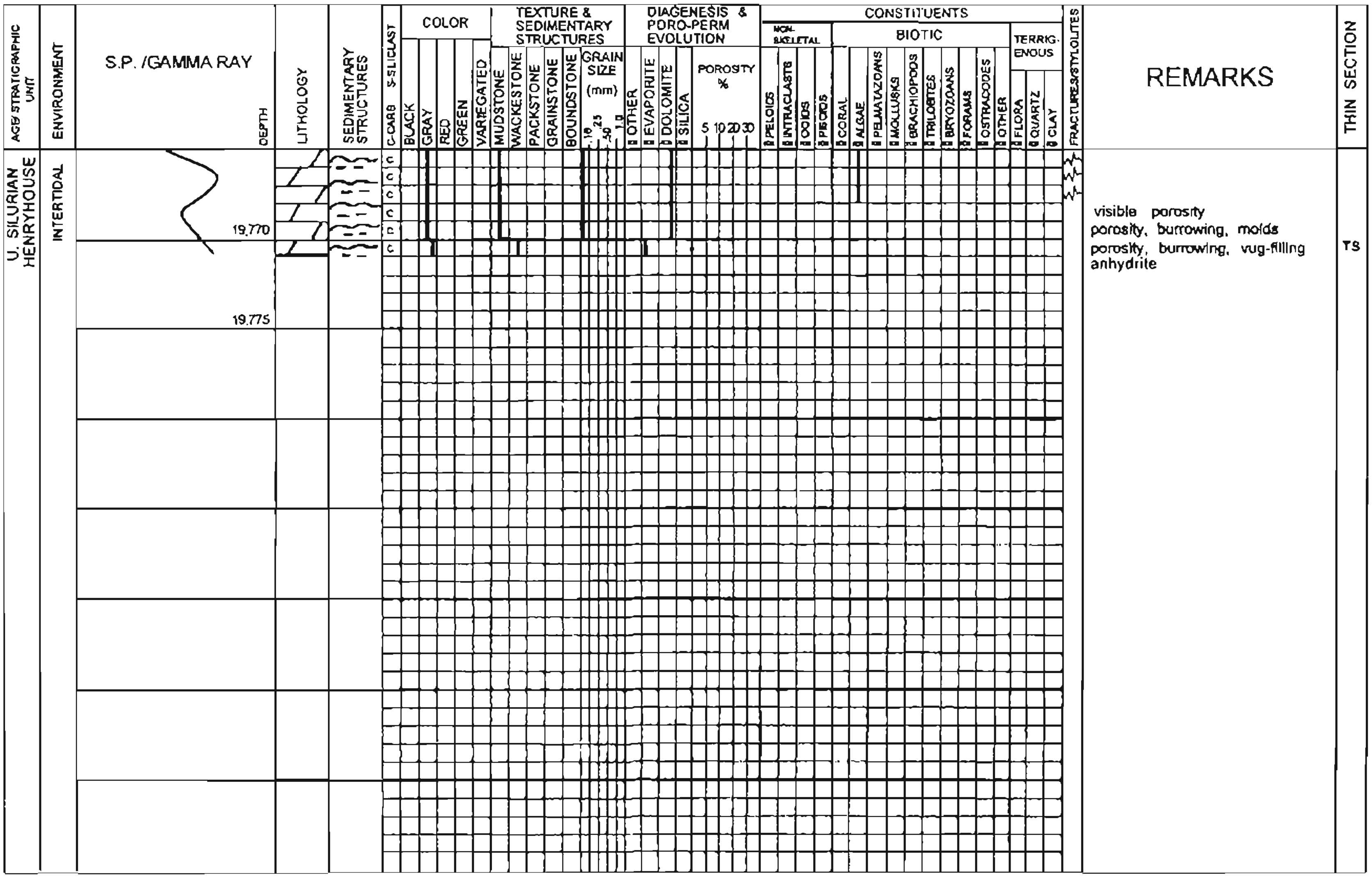
LOCATION Sec. 31, T.10N., R.26W. Beckham County, Oklahoma



COMPANY/WELL NAME Apexco (Natomas) Green No. 1

LOCATION Sec. 31, T.10N., R.26W. Beckham County, Oklahoma

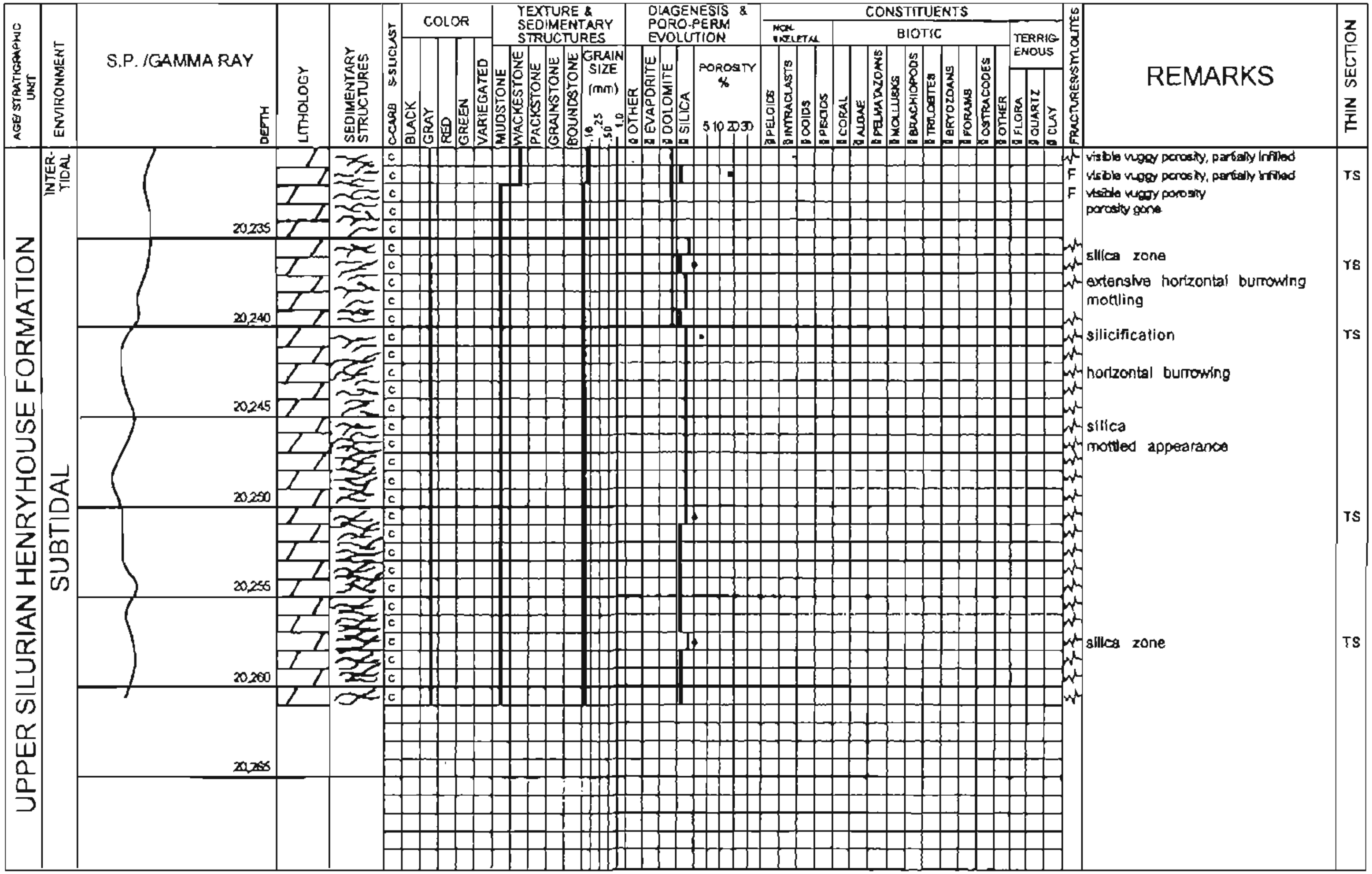
PETROLOGIC LOG



COMPANY/WELL NAME Apexco (Natomas) Green No. 1

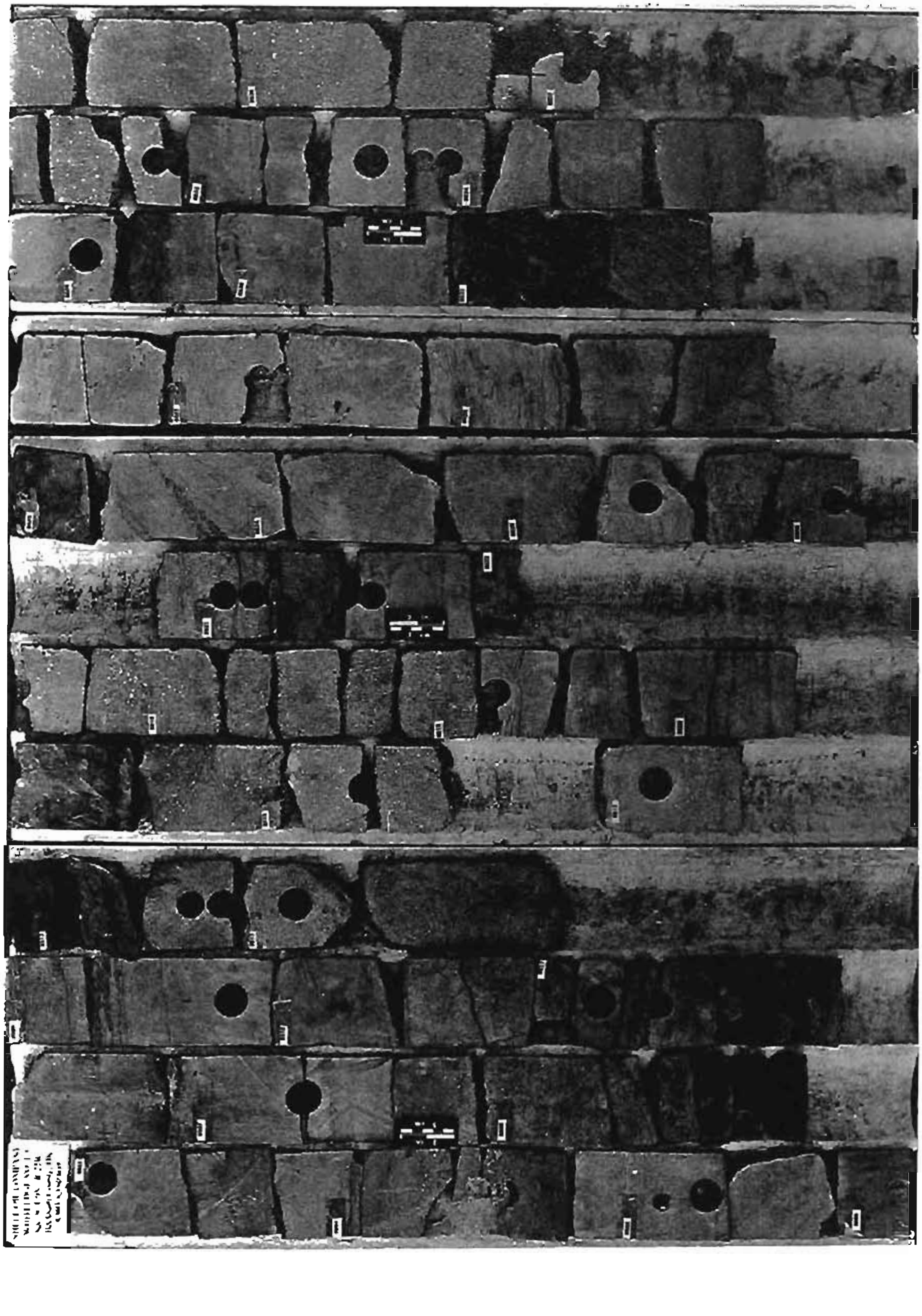
LOCATION Sec. 31, T.10N., R.26W. Beckham County, Oklahoma

PETROLOGIC LOG



APPENDIX B

CORE PHOTOGRAPHS

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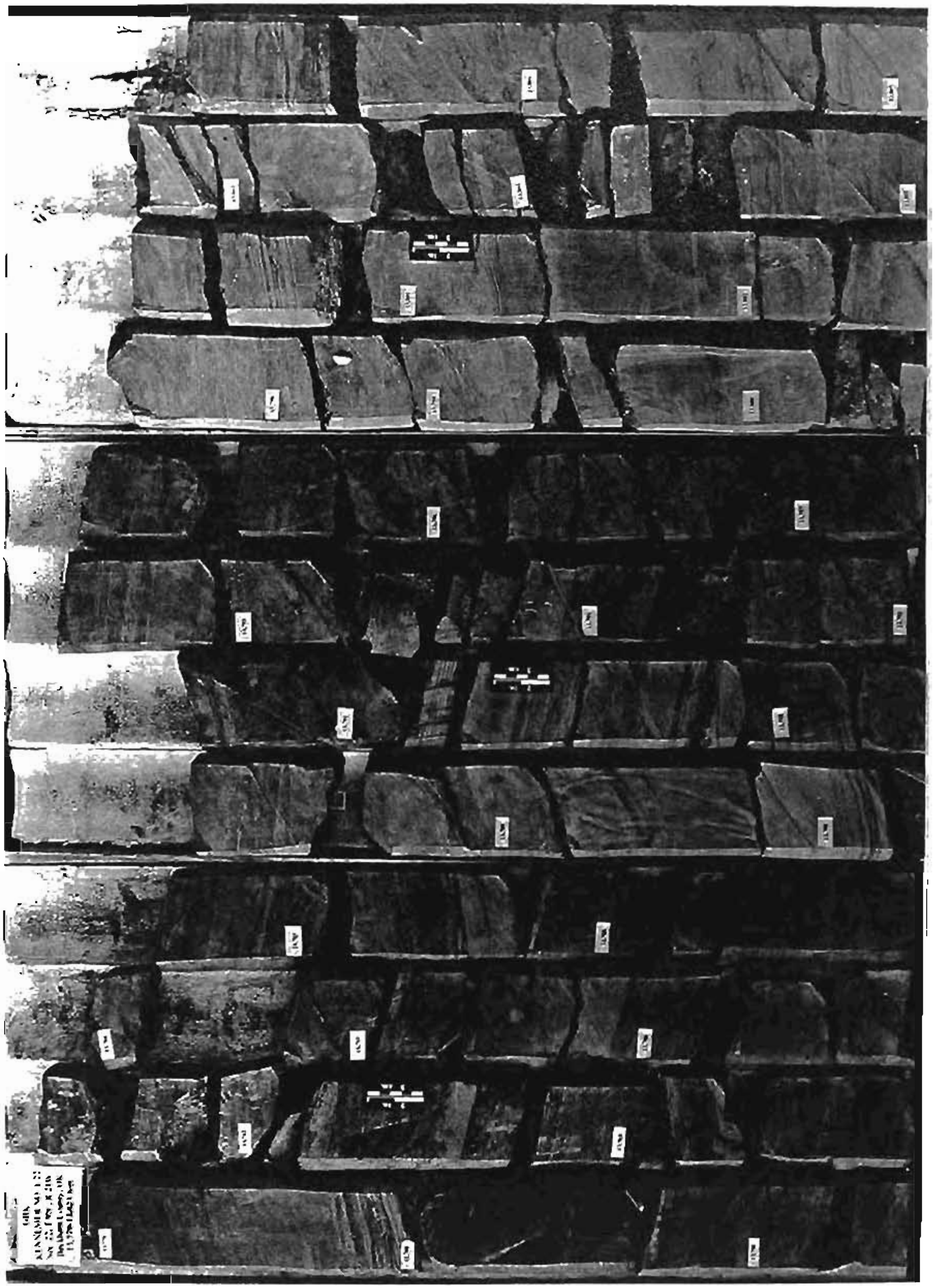

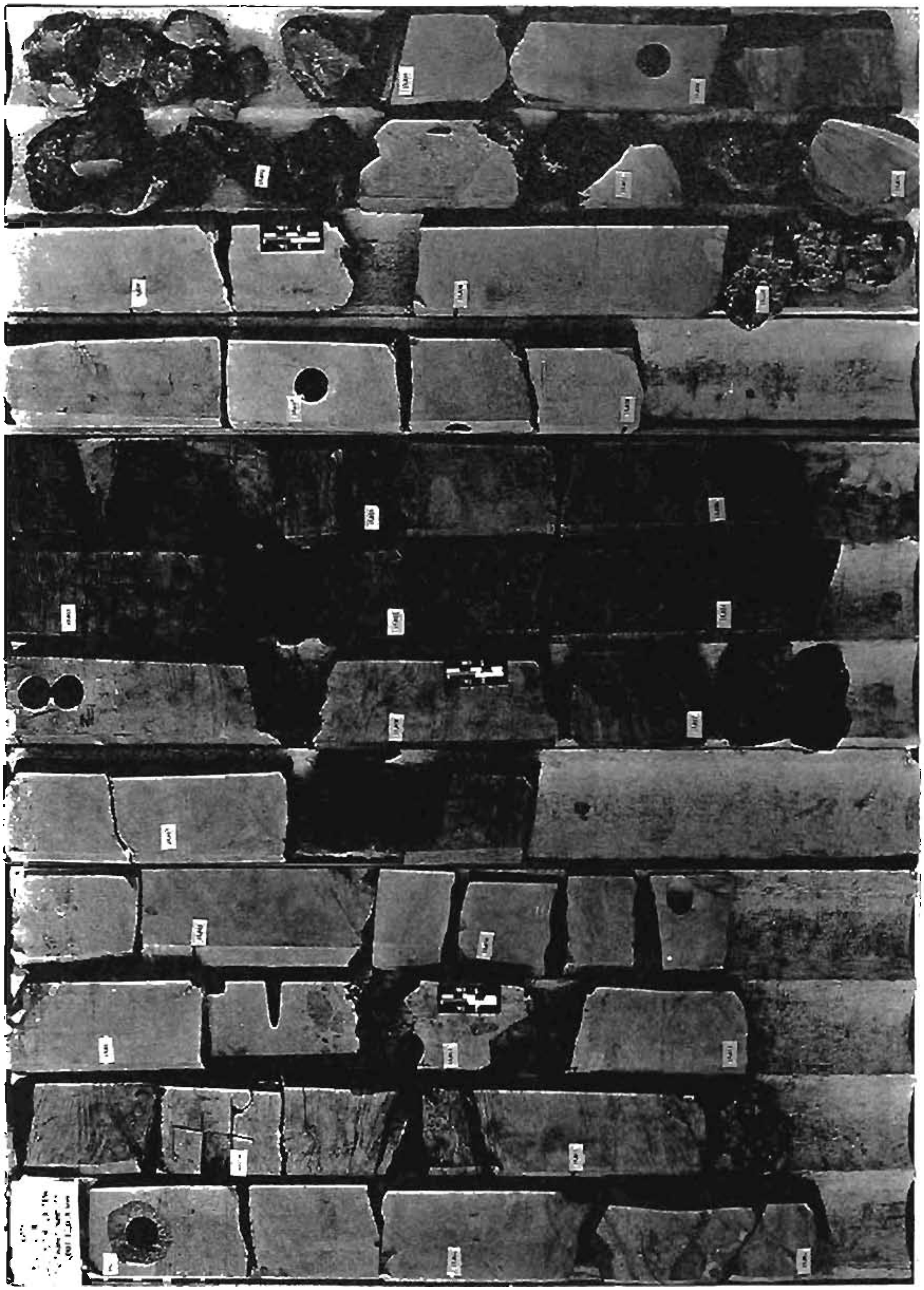


2 in.
5 cm.
2 in.
5 cm.

VITA

Catherine Lisa Price

Candidate for the Degree of

Master of Science

Thesis: FRONTAL FAULT ZONE OF THE WICHITA MOUNTAINS: IDENTIFICATION AND CHARACTERIZATION OF A FAULT-ASSOCIATED LATERAL SEAL

Major Field: Geology

Biographical:

Personal Data: Born in Oxford, England, on May 16, 1973, the daughter of Eric and Jean Price.

Education: Graduated from Stillwater High School, Stillwater, Oklahoma in May 1991; received Bachelor of Arts degree in Biochemistry from the University of Texas at Austin, Austin, Texas in May 1994. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State University in July 1997.

Experience: Employed by Oklahoma State University Department of Geology as a graduate research assistant, 1995 to present.